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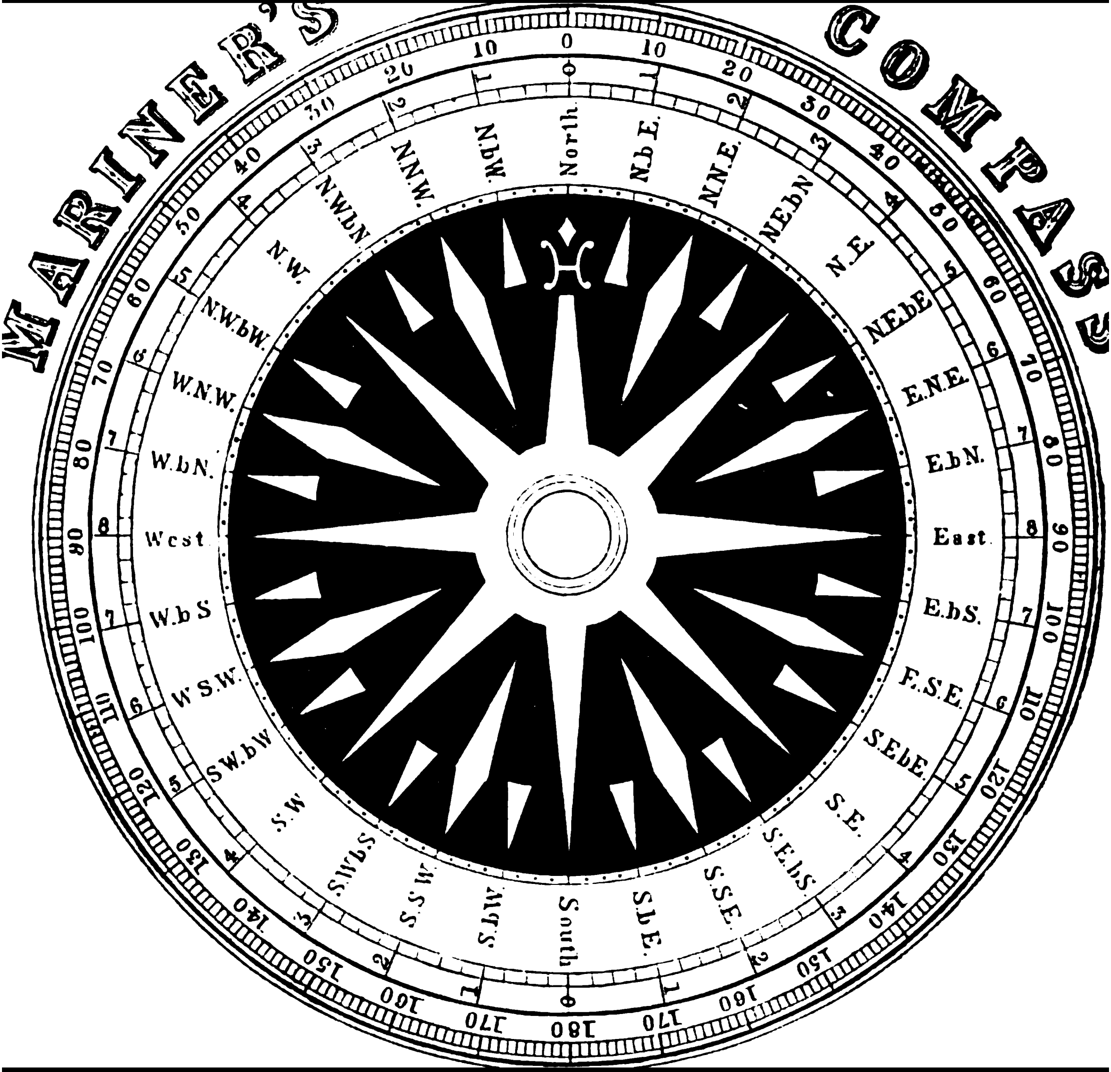
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N.b E.
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East
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South
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N.N.W.
N.b W.

A guide book to the Local marine board examination. ...

Thomas Liddell Ainsley

A

GUIDE BOOK

TO THE

LOCAL MARINE BOARD

EXAMINATION.

THE ORDINARY EXAMINATION.

iddle

BY THOMAS L. AINSLEY,

TEACHER OF NAVIGATION.

Forty-fifth Edition.

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PREFACE TO THE FIRST EDITION.

THIS WORK is intended as a Guide to the Officers of all grades of the Merchant Service, in the examinations they are required to undergo before the Local Marine Board. It will be issued in Two parts:—Part I containing what is termed the Ordinary Examination, and Part II containing the Extra Examination.

The present volume, which relates to the Ordinary Examination, contains model solutions of examples in the various problems required of Candidates when under Examination, with numerous Exercises to each Problem, together with a variety of Examination Papers. It also contains all requisite information respecting the Deviation of the Compass; Lights of the English, St. George's, and Bristol Channels, &c.; Stowage of Cargoes; Invoice; Charter Party; Bottomry Bonds, &c.

In the preparation of the articles on Seamanship, the following works have been consulted:—"The Kedge Anchor," by W. Brady, U.S.N.; "The Seaman's Friend," by R. H. Dana, jun; "The Sheet Anchor," by Darcy Lever, Esq.; while my obligations to other works have been duly acknowledged. The works of ABBOTT, LEES, STEELE, and M'CULLOCH, &c., are the authorities that have been consulted on the subjects of Charter Party, Bills of Lading, &c.

T. L. A.

South Shields, July 10th, 1856.

ADVERTISEMENT

TO

THE FORTY-FIFTH EDITION.

In this Edition of the "Guide Book," such alterations and additions have been made in the work as were necessary to adapt it to the present requirements of the Examinations—considerable alterations in the Examination Papers having recently come into operation.

T. L. A.

South Shields,
October 31st, 1885.

ERRATA ET CORRIGENDA.

Page 411, line 5 from top, for bunts, read banks.
„ „ line 18 from to, for until the, read until they.

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NOTICE OF

EXAMINATIONS OF MASTERS AND MATES

OF

FOREIGN-GOING SHIPS & HOME-TRADE PASSENGER SHIPS

AND OF

VOLUNTARY EXAMINATIONS IN STEAM.

1. UNDER the provisions of the Merchant Shipping Act, 1854, (17 and 18 Vict., c. 104, s.s. 136—161, no Foreign-going Ship[*] or Home Trade Passenger Ship[*] can obtain a clearance or transire, or legally proceed to sea, from any port in the United Kingdom, unless the Master thereof, and in the case of a Foreign-going Ship, the First and Second Mates or only Mate, (as the case may be), and in the case of a Home Trade Passenger Ship, the First or Only Mate, (as the case may be), have obtained and possess valid Certificates of Competency or Service, appropriate to their several stations in such ship, or of a higher grade; and no such ship, if of *one hundred tons burden or upwards*, can legally proceed to sea unless at *least one officer besides the Master* has obtained and possesses a valid Certificate appropriate to the grade of Only Mate therein, or to a higher grade; and every person who, having been engaged to serve as Master, or as First or Second or Only Mate of any Foreign-going Ship, or as Master or First or Only Mate of a Home Trade Passenger Ship, goes to sea as such Master or Mate, without being at the time entitled to and possessed of such a Certificate as the Act requires, or who employs any person as Master, or First, Second, or Only Mate of any Foreign-going Ship, or as Master or First or Only Mate of any Home Trade Passenger Ship, without ascertaining that he is at the time entitled to and possessed of such Certificate, *for each offence incurs a penalty not exceeding fifty pounds.*

2. Every Certificate of *Competency* for a Foreign-going Ship, is to be deemed to be of a higher grade than the corresponding Certificate for a Home Trade Passenger Ship, and entitles the lawful holder to go to sea in the corresponding grade in such last-mentioned Ship; but *no Certificate for a Home Trade Passenger Ship, entitles the holder to go to sea as Master or Mate of a Foreign-going Ship*, nor does a Certificate of Service entitle the possessor to act in a vessel of any class except that for which it is granted.

3. *Certificates of Competency* will be granted to those persons who pass the requisite examinations, and otherwise comply with the requisite conditions. For this purpose

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[*] By a Foreign-going Ship is meant one which is bound to some place out of the United Kingdom, beyond the limits included between the river Elbe and Brest; and by a Home Trade Passenger Ship is meant any Home Trade Ship employed in carrying Passengers; and it is to be observed that *Foreign Steam Ships when employed in carrying passengers between places in the United Kingdom*, are subject to all the provisions of the Act, as regards Certificates of Masters and Mates, to which British Steam Ships are subject. [S 291.]

examiners have been appointed, and arrangements have been made for holding examinations at the ports and upon the days mentioned below:—

PLACES.	FOR MASTERS AND MATES.
Aberdeen*	Wednesday in each week.
Belfast*	1st and 3rd Tuesday in each month.
Bristol*	2nd and 4th Tuesday in each month.
Cardiff	1st Tuesday in each month.
Cork	2nd and 4th Monday in each month.
Dublin	2nd and 4th Tuesday in each month.
Dundee*	Thursday in each week.
Glasgow*	Tuesday in each week, alternately with Greenock.
Greenock*	Tuesday in each week, alternately with Glasgow.
Hull	2nd and 4th Tuesday in each month.
Leith	2nd and 4th Tuesday in each month.
Liverpool	Monday and Thursday in each week.
London*	Monday in each week. Masters' voluntary examination in Steam held on Friday in each week.
Plymouth	Tuesday in each week.
Shields, South*	1st and 3rd (and 5th) Tuesday in each month.
Southampton*	1st and 3rd Thursday in each month.
Sunderland*	2nd and 4th Tuesday in each month.
Swansea*	1st and 3rd Tuesday in each month.

N.B.—The examination days are liable to occasional alteration, and Candidates are therefore advised to ascertain the actual date from the Superintendent of the Mercantile Marine Office.

4. The examinations will commence early in the forenoon on the days mentioned in the above list and will be continued from day to day until all the Candidates whose names appear upon the Superintendent's list on the day of examination are examined.

5. Candidates for examination must make their application upon the appropriate form (Exn. 2.) which must be filled up at a Mercantile Marine Office. The Exn. 2., properly filled in, together with the Candidate's testimonials and discharges, must be lodged with the Local Marine Board, if there is a Local Marine Board at the port, and if there is not, with the Superintendent of the Mercantile Marine Office, not later than the day before the day of examination (except in the case of London† and Liverpool), and the Candidate must conform to any regulations in this respect which may be laid down by the Local Marine Board or the Board of Trade, as if this be not done, delay may be occasioned.

6. *Testimonials of character, and sobriety, experience, ability, and good conduct on board ship for at least the twelve months of service immediately preceding the date of application to be examined, will be required of all applicants, and without producing them no person will be examined.* As such testimonials and discharges may have to be forwarded to the Office of the Registrar-General of Seamen in London for verification before the Candidate can be examined, it is desirable that they should be handed in together with the Form Exn. 2. as early as possible.

7. The testimonials of servitude of Foreigners and of British Seamen serving in foreign vessels, which cannot be verified by the Registrar-General of Seamen, must be confirmed either by the Consul of the country to which the ship in which the candidate served belonged, or by some other recognised official authority of that country, or by the testimony of some credible person on the spot having personal knowledge of the facts required to be established. The production, however, of such proofs will not of necessity be deemed sufficient. Each case will be decided on its own merits, and if the sufficiency of the proofs given appears to be at all doubtful, it must be referred to the Board of Trade.

8. Should any doubt exist as to the age of a Candidate, he will be required to produce a certificate of birth.

---

* At these places Masters' Extra Examinations are held.

† At London applications for examination must be made on Fridays from 10 till 4, and on Saturdays from 10 till 2.

At Liverpool applications for examination must be made on Wednesdays and Saturdays during office hours.

9. Foreigners must prove to the satisfaction of the Examiners that they can speak and write the English language sufficiently well to perform the duties required of them on board a British Vessel.

10. A Statement of Services, verified by the Registrar-General of Seamen, may at any time be obtained by application to that officer, upon payment of a small fee, the amount of which will be regulated by the amount of Service which is required to be verified. Delay, inconvenience, and disappointment are frequently avoided by a Candidate getting this verification beforehand.

11. Services which cannot be verified by proper Entries in the Articles of the Ships in which the Candidates have served cannot be counted. For instance, a man will state his service to have been as Second or Only Mate, and to support his assertion will produce a Certificate of Discharge or of employment by the Master, to the effect that he served as Mate, when on reference to the Articles it appears that he has actually been rated at Boatswain; the service in such a case will not be regarded as having been in the capacity of Mate.

12. Whenever a man has, from any cause, been regularly promoted on a vacancy in the course of the Voyage from the rank in which he first shipped, and such promotion, with the ground on which it has been made, is properly entered in the Articles and in the Official Log Book, he will of course receive credit for his service in the higher grade for the period subsequent to his promotion.

13. Service in the coasting trade may be allowed to count as service, in order to qualify a Candidate for examination for a Certificate of Competency for Foreign-going Ships, it being understood, however, that service in a lower grade than that of First or Only Mate in the coasting trade will not be recognised as officer's service. Two years' service as Mate, in the coasting trade, together with at least six months' service as Master, may be allowed to count as service for a Master's Certificate for Foreign-going Ships, provided the Candidate's entire service at sea amounts to six years, and his services as Mate and Master in the coasting trade can be proved by the articles, and provided he has already passed an examination *for the Foreign Trade*, unless, *under special circumstances*, the Board of Trade see fit to dispense with this latter provision.

14. Time for which Indentures of Apprenticeship are in force will be accepted as sea service, provided that the Apprentice has remained by the ship all the time, and the Indentures of the applicant are endorsed by the Owner or Master to whom he has been bound, to the effect that he has performed his service faithfully for the whole time agreed upon and provided also that the Local Marine Board are satisfied that no undue amount of service has been performed on shore. In the event of the Local Board being of opinion that the amount of service performed by the Candidate on shore has been excessive, they may determine how much further sea service shall be required of him before he may present himself for examination.

15. Part of the time served on board a training ship will be allowed to count as service at sea, provided that the Candidate can produce amongst his testimonials a Certificate from the Committee that he has conducted himself creditably, and passed a good examination in seamanship so far as practised in the training ship as well as in other matters down to the time of his leaving the ship.

16. No period of service on board a training ship will be allowed to count for more than one year's sea service, nor can it be accepted as equivalent to service in square-rigged vessels.

17. Service in Auxiliary Screw Whaling Ships and other Vessels with auxiliary steam power, which use their screws only in calms or during light winds, is considered as service performed in Sailing Vessels. Such service is not to be accepted in cases where service on board Foreign-going Steamships is required.

18. Candidates whose services have been in capacities other than Apprentice, Ordinary Seaman, or Able Seaman, *e.g.*, Cook, Steward, Carpenter, &c., will be required to satisfy the Board of Trade or a Local Marine Board that they have a good knowledge of Seamanship. This may possibly be proved by the production of satisfactory Certificates from

Masters with whom the Applicants have served. Failing satisfactory evidence, the Applicant may be required to perform additional service, which must be in the capacity of Ordinary Seaman or Able Seaman.

19. It is provided by the Merchant Shipping Act, 1854 (sec. 140), that every person who makes or procures to be made, or assists in making, any false representation for the purpose of obtaining for himself or for any other person a Certificate of Competency, shall for each offence be deemed guilty of a misdemeanor,—the punishment for which is imprisonment for any period not exceeding six months, with or without hard labour, or a penalty not exceeding one hundred pounds.

20. These provisions will be *strictly enforced* by the Board of Trade, and any Candidate for a Certificate of Competency as Master, or as First, or Second, or Only Mate, in the Merchant Service, who shall, knowingly and fraudulently, for the purpose of obtaining any such Certificate, present to the Examiner any "application to be examined for a Certificate of Competency" (Exn. 2.), or statutory declaration containing any false or inaccurate statement of service, and any person who shall knowingly and fraudulently make or prepare, or assist in making or preparing any such false or inaccurate statement will be *prosecuted*.

21. If after a Candidate has passed his Examination it is discovered on further investigation, *e.g.*, by verification on the part of the Registrar-General of Seamen, that his services are insufficient to entitle him to receive a Certificate of the grade for which he has passed, it will not be granted to him; but if the Board of Trade are satisfied that the error in the calculation of his services did not occur through any fault or wilful misrepresentation on his part, he will be allowed to go up for re-examination without payment of further fee when he has performed the amount of service in which he was deficient.

22. If, in such a case, the applicant's services are sufficient to entitle him to receive a Certificate of a lower grade, provided as aforesaid he has not wilfully misrepresented the amount of his services, an Inferior Certificate may be granted to him, and the difference, if any, between the fee paid by him for the Superior Certificate and the fee payable for the Inferior Certificate may be placed to his credit.

23. In such a case when the applicant has by further service, made up the amount in which he was found to be short, he must, before he can receive the higher Certificate, be re-examined in all the subjects.

COLOUR BLINDNESS.

24. The Board of Trade have made the following arrangements for the examination of persons as to their ability to distinguish colours.

25. Examinations in colour are open to any person serving or about to serve in the Mercantile Marine.

26. Any person desirous of being examined must make application to a Superintendent of a Mercantile Marine Office on Form Exn. 2a, and pay a fee of one shilling.

27. He must on the appointed day attend for examination at the Examiner's Office; and if he passes he will receive a Certificate to that effect.

28 The examination of a Candidate for a Master's or Mate's Certificate will commence with the colour test, and if he does not at the time of making application hold a Certificate of Competency of any grade, and he should fail to distinguish correctly any one of the colours used in that test, he will not be allowed to present himself for examination in navigation and seamanship.

29. The fee he has paid for examination for a Certificate of Competency will include the fee for the colour test, and, with the exception of one shilling, will be returned to him.

30. A Candidate who fails to pass the test may be re-examined after the lapse of three months from the date of his first failure. If he fails a second time he will be allowed a third trial at the expiration of another three months from the date of his second failure. A fresh fee must be paid at each succeeding examination.

31. A Candidate who holds a Certificate of Competency and who on presenting himself for examination for a Certificate of a higher grade is unable to pass the colour test, will notwithstanding be permitted to proceed in the examination in navigation and seamanship for the Certificate of the higher grade.

32. Should he pass this examination, the following statement will be written on the face of the higher Certificate which may be granted to him, viz.: "This officer has failed to pass the examination in colours."

33. Should he fail to pass the examination in Navigation and Seamanship a like statement, relating to his being colour blind, will be made on his inferior Certificate before it is returned to him.

34. Holders of Certificates which bear the statement of their having failed to pass in Colours, and who may desire to be re-tested in Colours, must obtain the special permission of the Board of Trade.

35. Ports at which examinations in Colour take place are as follows:—

Aberdeen.—Examiner of Masters and Mates. (Wednesday and Thursday in each week.)
Belfast.—Examiner of Masters and Mates. (Any day.)
Bristol.—Examiner of Masters and Mates. (Second and fourth Tuesday and following Wednesday in each month.)
Cardiff.—Principal Officer of the Board of Trade. (Any day.)
Cork.—Examiner of Masters and Mates. (Any day.)
Dublin.—Examiner of Masters and Mates. (Any day.)
Dundee.—Examiner of Masters and Mates. (Thursday and Friday in each week.)
Glasgow.—Examiner of Masters and Mates. (Tuesdays and Wednesdays in Examination weeks for Masters and Mates.)
Greenock.—Examiner of Masters and Mates. (Tuesdays and Wednesdays in Examination weeks for Masters and Mates.)
Hull.—Examiner of Masters and Mates. (Second and fourth Tuesday and following Wednesday in each month.)
Principal Officer of the Board of Trade. (Any day.)
Leith.—Examiner of Masters and Mates. (Any day.)
Liverpool.—Examiner of Masters and Mates. (Wednesday and Saturday in each week.)
London.—Examiner of Masters and Mates. (Monday and Tuesday in each week.)
North Shields.—Principal Officer of the Board of Trade. (Any day.)
Plymouth.—Examiner of Masters and Mates. (Any day.)
Southampton.—Superintendent of the Mercantile Marine Office. (Any day.)
South Shields.—Examiner of Masters and Mates. (Thursdays and Fridays in Examination weeks for Masters and Mates.)
Sunderland.—Examiner of Masters and Mates. (Thursdays and Fridays in Examination weeks for Masters and Mates.)
Swansea.—Board of Trade Officer. (Any day.)

QUALIFICATIONS FOR CERTIFICATES OF COMPETENCY FOR A "FOREIGN-GOING SHIP."

36. **Examination in Colours.**—All Candidates for Certificates of Competency must pass the examination in Colours.

37. **A SECOND MATE** must be seventeen years of age, and must have been four years at sea. He must also prove that he has served at least one year in a square-rigged sailing vessel.

38. **In Navigation, &c.**—He must write a legible hand, and will be required to give in writing definitions of various astronomical and other terms used in navigation. He must have a competent knowledge of the first five rules of arithmetic, and the use of logarithms. He must be able to work a day's work complete, correcting the courses for deviation, leeway, and variation. He will be required to find the latitude by meridian altitude of the sun, and the difference of longitude from a given departure by parallel sailing; also to find the

course and distance from one position to another by Mercator's method. He will be required to find the time of high water at a given port, to observe and calculate the amplitude of the sun, and to find the error of the ship's compass therefrom, and also the deviation, the variation being given. He must be able to find the daily rate of the chronometer from error observed, and to find the longitude from altitude of the sun by the usual methods. He must understand the use of the sextant, with its adjustments, and be able to observe with it, find the index error by the horizon, and read off and on the arc. He must also pass a satisfactory examination in the International Code of Signals.

39. **In Seamanship, &c.**—He must give satisfactory answers as to the standing and running rigging of ships; as to bending, unbending, setting, reefing, taking in and furling sail; as to sending masts and yards up and down, &c.; as to the management of a ship when under canvas; and as to dunnaging and stowing cargo, &c. He must have a thorough knowledge of the rule of the road as regards both steamers and sailing vessels, their regulation lights, and fog, and sound signals, and be able to describe the signals of distress, and the signals to be made by ships wanting a pilot, and the liabilities and penalties incurred by the misuse of these signals. He must be able to mark and use the lead and log lines. He must also understand the use and management of the rocket apparatus in the event of his vessel being stranded, and other questions of a like nature, appertaining to the duties of the Second Mate of a ship, which the Examiner may think necessary to put to him. He will also be required to give satisfactory answers as to his knowledge of the additional subjects (applying more particularly to steamships) which are specified in the Rules of Examination for Second Mates' Certificates of Competency for Foreign-going Steamships.

40. **An ONLY or FIRST MATE.**—An Only Mate must be nineteen years of age, and must have served five years at sea. A First Mate must be nineteen years of age, and must have served five years at sea, of which one year must have been as Second or Only Mate. He must also prove that he has served at least one year in a square-rigged sailing vessel.

41. **In Navigation.**—In addition to the qualifications required for a Second Mate, an Only or First Mate must be able to find the true bearing of the sun and the error of the ship's compass from an observed azimuth of the sun, both from an altitude and also from the "Time Azimuth Tables," and with the variation given compute the deviation; to find the latitude from a single altitude of the sun off the meridian, and to be able to use and adjust the sextant, and to find the index error by the sun; and also to ascertain the true bearing of the sun, &c., and the ship's position by Sumner's method by projection. He must also be conversant with the use of Mercator's Chart, and be able to find, on either a "true" or "magnetic" chart, the course to steer and the distance from one given position to another; and find the ship's position on the chart from cross bearings of two objects; from two bearings of the same object, the course and distance between the bearings being given; and also the distance of ship from the object at the time of taking the second bearing. He must also understand how to keep a ship's Log Book.

42. **In Seamanship, &c.**—In addition to the qualifications required for a Second Mate, a more extensive knowledge of seamanship will be required, as to shifting large spars, rigging sheers, taking lowermasts in and out, how to moor and unmoor ship, and to keep a clear anchor; to carry out an anchor; how to manage a ship in stormy weather; how to cast a ship on a lee shore; how to secure the masts in the event of accident to the bowsprit; and how to rig purchases for getting heavy weights, anchors, machinery, &c., in and out. He must give satisfactory answers as to the ventilation of holds and the stowage of explosives. He must also know how to rig a sea anchor, and what means to apply to keep a vessel disabled or unmanageable out of the trough of the sea, and lessen her lee drift. How to get a cast of deep sea lead in heavy weather; and answer any other questions appertaining to the duties of an Only or First Mate of a ship which the Examiner may think necessary to put to him. He will also be required to give satisfactory answers as to his knowledge of the additional subjects (applying more particularly to steamships) which are specified in the Rules of Examination for Only and First Mates' Certificates of Competency for Foreign-going Steamships.

43. **A MASTER** must be twenty-one years of age, and have been six years at sea, of which one year must have been as First or Only Mate in a Foreign-going Ship, and one year as Second or Only Mate; or he must have been six and a half years at sea, of which two and a half years must have been as Second Mate of a Foreign-going Ship, during the last twelve months of which service as Second Mate he must have been in possession of a First Mate's Certificate. He must also prove that he has served at least one year in a square-rigged sailing vessel in the capacity of either Apprentice, Seaman, Mate, or Master. *Vide also par. 13.*

44. **In Navigation.**—In addition to the qualifications required for a Second, Only, and First Mate he must be able to compute the latitude from the meridian altitude of a star, &c. He must be able to find the magnetic bearing from equidistant compass bearings of any fixed object when at sea, and compute the deviation therefrom. He must construct a deviation curve upon a "Napier's" diagram which will be furnished by the Examiner, and understand the practical application of the same, and give written answers to certain practical questions on the effect of the ship's iron upon the compasses, the method of determining the deviation, and compensating same by magnets and soft iron. He will be required to find the course to steer by compass in order to counteract the effect of a given current, and find the distance the ship will make good towards a given point in a certain time, and to work out practically the correction to apply to soundings taken at a given time and place, to compare with the depth marked on the chart.

45. **In Seamanship.**—In addition to the qualifications required of a Second, Only, and First Mate, he must be able to construct jury rudders for both wooden and iron vessels, and also rafts. He will be examined as to his resources for the preservation of the ship's crew in the event of a wreck; as to the management of ships in heavy weather; as to the rescuing the crew of a disabled ship; as to steps to be taken when a ship is on her beam ends, or in any danger or difficulty; or if disabled or unmanageable and on a lee shore; heaving a keel out, &c. He must explain the mode of procedure when placing ship in dry dock, directing repairs, and if putting into port in distress with damage to cargo and ship. He must possess a sufficient knowledge of what he is required to do by law, as to entry and discharge, and the management of his crew, and as to penalties, and entries to be made in the official log, and a knowledge of the measures for preventing and checking the outbreak of scurvy on board ship, and the law as to the load line marks and the entries and reports to be made respecting them. He will be questioned as to his knowledge of invoices, charter party, bills of lading, Lloyd's agent, and as to the nature of bottomry, also bills of exchange, surveys, averages, &c., and must answer any other questions of a like nature appertaining to the management of a ship which the Examiner may consider it necessary to touch upon. He will also be required to give satisfactory answers as to his knowledge of the additional subjects (applying more particularly to steamships) which are specified in the Rules of Examination for Masters' Certificates of Competency for Foreign-going Steamships.

CERTIFICATES FOR FORE AND AFT RIGGED VESSELS.

46. Certificates for the grades of Master, First Mate, Only Mate, and Second Mate, on which the words "for Fore and Aft rigged vessels only" will be written, will be issued to Candidates who have not complied with the regulation which requires them to have served at least one year in square-rigged *sailing* vessels, or who prove in course of examination that they are ignorant of the management of square-rigged ships.

47. A certificate "for Fore and Aft rigged vessels only" will not entitle the possessor to act in a capacity for which a certificate is required in square-rigged vessels, amongst which are classed full-rigged ships, barques, brigs, barquentines, brigantines, and steam ships carrying square sails.

48. A Candidate possessing a certificate "for Fore and Aft rigged vessels only," and desiring to obtain an ordinary certificate of the same grade, must prove that he has served at sea at least one year in a square-rigged *sailing* vessel, and will be re-examined both in navigation and seamanship.

QUALIFICATIONS FOR CERTIFICATES OF COMPETENCY FOR FOREIGN-GOING STEAMSHIPS ONLY.

49. Certificates of Competency will be issued, subject to the examinations herein-after described, for officers who have served in steamships, and who, owing to absence of service in square-rigged sailing ships, cannot under the existing regulations obtain Certificates of Competency to act in the capacity of Masters or Mates of square-rigged steamships.

50. These certificates will entitle the holders to go to sea as Masters and Mates of foreign-going steamships, but will not entitle the holders to go to sea as Masters or Mates of foreign-going sailing ships.

51. There will be no distinction in respect of "Fore and Aft" and "Square-rigged" steamships.

52. **Examination in Colours.**—All Candidates for Certificates of Competency must pass the examination in Colours.

53. **A SECOND MATE** must be 17 years of age, and must have been four years at sea.

54. **In Navigation, &c.**—He must write a legible hand, and will be required to give in writing definitions of various astronomical and other terms used in navigation. He must have a competent knowledge of the first five rules of arithmetic, and the use of logarithms. He must be able to work a day's work complete, correcting the courses for deviation, leeway, and variation. He will be required to find the latitude by meridian altitude of the sun, and the difference of longitude from a given departure by parallel sailing; also to find the course and distance from one position to another by Mercator's method. He will be required to find the time of high water at a given port, to observe and calculate the amplitude of the sun, and to find the error of the ship's compass therefrom, and also the deviation, the variation being given. He must be able to find the daily rate of the chronometer from error observed, and to find the longitude from altitude of the sun by the usual methods. He must understand the use of the sextant with its adjustments, and be able to observe with it, find the index error by the horizon, and read off and on the arc. He must also pass a satisfactory examination in the International Code of Signals.

55. **In Seamanship, &c.**—He must give satisfactory answers as to the standing and running rigging of Steamships; as to bending, unbending, setting, reefing, taking in and furling sail; as to sending masts and yards up and down, &c., &c.; as to seeing everything in readiness and clear for getting under way, and as to the precautions to be then observed with regard to engines, propeller, &c.; as to the management of a steamship when under canvas; and as to dunnaging and stowing cargo, &c. He must have a thorough knowledge of the rule of the road as regards both steamers and sailing vessels, their regulation lights, and fog, and sound signals, and be able to describe the signals of distress, and the signals to be made by ships wanting a pilot, and the liabilities and penalties incurred by the misuse of these signals. He must be able to mark and use the lead and log lines. He must also understand the construction, use, and action of the sluices, and of the water-ballast tanks, engine room telegraph, &c.; the use and management of the rocket apparatus in the event of his vessel being stranded, and other questions of a like nature, appertaining to the duties of the Second Mate of a steamship, which the Examiner may think necessary to put to him.

56. **An ONLY or FIRST MATE.**—An Only Mate must be 19 years of age, and must have served five years at sea. A First Mate must be 19 years of age and must have served five years at sea, of which one year must have been as Second or Only Mate of a foreign-going steamship.

57. **In Navigation.**—In addition to the qualifications required for a Second Mate, an Only or First Mate must be able to find the true bearing of the sun and the error of the ship's compass from an observed azimuth of the sun, both from an altitude and also from the "Time Azimuth Tables," and with the variation given compute the deviation; to find the latitude from a single altitude of the sun off the meridian, and be able to use and adjust the sextant, and to find the index error by the sun; and also to ascertain the true bearing of the sun, &c., and the ship's position by Sumner's Method by Projection. He must also be conversant with the use of Mercator's chart and be able to find, on either a "true" or

"magnetic" chart, the course to steer and the distance from one given position to another; and find the ship's position on the chart from cross bearings of two objects; from two bearings of the same object, the course and distance between the bearings being given; and also the distance of ship from the object at the time of taking the second bearing. He must also understand how to keep a ship's Log Book.

58. **In Seamanship.**—In addition to the qualifications required for a Second Mate, a more extensive knowledge of seamanship will be required, as to shifting large spars, rigging sheers, taking lower masts in and out, how to moor and unmoor ship and to keep a clear anchor, to carry out an anchor; how to manage a steamship in stormy weather, and how to rig purchases for getting heavy weights, anchors, machinery, &c., in and out. He must give satisfactory answers as to the ventilation of holds, and the stowage of explosives. He must be able to describe the effects of the screw race upon the rudder; and the affect produced on the direction of the head of the ship by going [ahead] [astern] with a [right] [left] handed screw when the rudder is [ported] [starboarded]. He must also know how to rig a sea anchor, and what means to apply to keep a steamer with machinery disabled out of the trough of the sea, and lessen her lee drift. How to turn a steamship short round; how to get cast of deep sea lead in heavy weather, and other questions of a like nature appertaining to the duties of an Only or First Mate of a steamship, which the Examiner may think necessary to put to him.

59. **A MASTER** must be 21 years of age, and have been six years at sea, of which one year must have been as First or Only Mate in a Foreign-going Steamship, and one year as Second or Only Mate; or he must have been six and a half years at sea, of which two and a half years must have been as Second or Only Mate in a Foreign-going Steamship, during the last 12 months of which he must have been in possession of a First Mate's Certificate.

60. **In Navigation.**—In addition to the qualifications required for a Second, Only, and First Mate, he must be able to compute the latitude from the meridian altitude of a star, &c.; he must be able to find the magnetic bearing from equidistant compass bearings of any fixed object when at sea, and compute the deviation therefrom. He must construct a deviation curve upon a "Napier's" diagram which will be furnished by the Examiner, and understand the practical application of the same, and give written answers to certain practical questions on the effect of the ship's iron upon the compasses, the method of determining the deviation, and compensating same by magnets and soft iron. He will be required to find the course to steer by compass in order to counteract the effect of a given current, and find the distance the ship will make good towards a given point in a certain time, and to work out practically the correction to apply to soundings taken at a given time and place, to compare with the depth marked on the chart.

61. **In Seamanship, &c.**—In addition to the qualifications required of a Second, Only, and First Mate, he must be able to construct rafts and jury rudders suitable for a screw steamship. He will be examined as to his resources for the preservation of the ship's crew in the event of wreck; as to the management of steamships in heavy weather; as to rescuing the crew of a disabled ship; as to steps to be taken when a ship is on her beam ends; or if disabled and on a lee shore. How to use steam appliances in the event of fire, and the best arrangement for towing vessels under different circumstances, placing ship in dry dock, directing repairs, and the mode of procedure if putting into port in distress with damage to cargo and ship. He must possess a sufficient knowledge of what he is required to do by law, as to entry and discharge, and the management of his crew, and as to penalties, and entries to be made in the official log, and a knowledge of the measures for preventing and checking the outbreak of scurvy on board ship, and the law as to load line marks, and the entries and reports to be made respecting them. He will be questioned as to his knowledge of invoices, charter-party, bills of lading, Lloyd's agent, and as to the nature of bottomry, also bills of exchange, surveys, averages, &c., and answer any other questions of a like nature, appertaining to the management of a steamship, which the Examiner may consider it necessary to touch upon.

QUALIFICATIONS FOR CERTIFICATES OF COMPETENCY FOR A "HOME TRADE PASSENGER SHIP."

62. All Candidates for Certificates of Competency must pass the examination in Colours.

63. A **MATE** must be 19 years of age, and have served four years at sea.

64. **In Navigation, &c.**—He must write a legible hand, and understand the first five rules of arithmetic. He must be able to take a bearing by compass, and be conversant with the use of Mercator's Chart, and be able to find, on either a "true" or "magnetic" chart, the course to steer, and the distance from one given position to another; to find the ship's position on the chart from cross bearings of two objects; from two bearings of the same object, the course and distance between the bearings being given; and also to find the distance of the ship from the object at the time of taking the second bearing.

65. He must also pass an examination in the International Code of Signals.

66. **In Seamanship, &c.**—He must possess a thorough knowledge of the Rule of the Road as regards both steamers and sailing vessels, their regulation lights, and fog, and sound signals. He must be able to describe the signals of distress, and the signals to be made by ships wanting a pilot, and the liabilities and penalties incurred by the misuse of these signals; also the use and management of the Rocket Apparatus in the event of his vessel being stranded. He must be able to mark and use the lead and log lines, to moor and unmoor a vessel, &c., &c. He must also understand the construction, use, and action of the bulkhead sluices, the engine-room telegraph, &c., and to answer any other questions of a like nature appertaining to the duties of the Mate of a Home Trade Passenger Vessel which the Examiner may think proper to put to him.

67. A **MASTER** must be 20 years of age, and have served five years at sea, of which one year must have been as First or Only Mate in the Home or Foreign Trade, during which service he must have been in possession of a Mate's Certificate for Home Trade Passenger Ships or of a First or Only Mate's Certificate for Foreign-going Ships.

68. **In Navigation, &c.**—In addition to the qualifications required of a Mate of a Home Trade Passenger Ship, a Master will be required to find on a chart the course to steer by compass in order to counteract the effect of a given current, and to find the distance the ship will make good towards a given point in a certain time, and to *work out practically* the correction to apply to soundings taken at a given time and place, to compare with the depth marked on the chart, &c.

69. **In Seamanship.**—In addition to the qualifications required of a Mate of a Home Trade Passenger Ship, a Master must understand how to rig a sea anchor, and what means to apply to keep a steamer with machinery disabled out of the trough of the sea, &c. How to get a cast of the lead in heavy weather, &c. He will be examined as to his resources for the preservation of the crew and passengers in the event of wreck, and the steps to be taken if his vessel is disabled and drifting towards a lee shore, and will be required to answer any other questions appertaining to the management of a Home Trade Passenger Vessel which the Examiner may think necessary to put to him.

FAILURE.

70. In all cases of failure the Candidate must be examined *de novo*. If a Candidate fails in *Seamanship* he will not be re-examined *until after a lapse* of SIX MONTHS. Whether the whole or part of this period must be served at sea must depend upon the subjects in Seamanship in which the Candidate failed, but what amount (if any) of sea service will be required will be left to the discretion of the Local Marine Board, subject, however, to revision by the Board of Trade, should they see fit.

71. The Examiner in making out his Report on Form Exn. 14, should state what amount (if any) of further sea service the Candidate must perform, and he should also insert this information under Division H. in Form Exn. 2.

72. If he fails three times in *Navigation* he will not be re-examined until after a lapse of THREE MONTHS from the date of the *last failure*.

73. If a Candidate has failed in his Examination, but the subjects in which he has failed are not included in the subjects required for a Certificate of a lower grade, he may, if he desires it, receive a Certificate of such lower grade.

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74. No part, however, of the fee he has paid will be returned to him, and on presenting himself, when entitled, for re-examination for the higher grade of Certificate he will be required to pay a further full fee.

FEES.

75. Candidates for examination, in making their application on Form Exn. 2, will be required to pay the examination fee before any step is taken, whether by enquiring into their services or testing their qualifications, &c. Should it be found that their service is not sufficient to entitle them to be examined, or should their testimonials be unsatisfactory, or should they from any other cause not be examined, no part of the fee will be returned to them, but when they have fulfilled the requisite service, or are able to produce satisfactory testimonials, as the case may be, they will be allowed to again present themselves for examination for a certificate of the same grade without paying any further fee.

76. The fee for examination must be paid to the Superintendent of the Mercantile Marine Office in the cash office. In any case in which a Candidate offers money to any other officer than a Superintendent, and in any place but in the cash office, the Candidate so offering money will be regarded as having committed an act of misconduct, and will be rejected, and not allowed to be again examined for twelve months either at the port where the offence was committed, or at any other port.

77. If a Candidate fail in his examination *no part of the fee will be returned to him.*

The fees are as follow:—

FOR "FOREIGN-GOING SHIPS."

Second Mate	£1 0 0
First and Only Mate, if previously possessing an inferior certificate, either granted by the Board of Trade, or by the Government of a British possession *under section* 8 *Merchant Shipping (Colonial) Act*, 1869"	0 10 0
If not	1 0 0
Master	2 0 0
Where a Candidate is in possession of a Certificate for Fore and Aft rigged Vessels; for an Ordinary or Steamship Certificate of the same grade	Half the usual fee.
Master Extra, if possessing an Ordinary Master's Certificate, first attempt	Nil.
Master Extra, for every subsequent attempt	1 0 0*

FOR "HOME TRADE PASSENGER SHIPS."

Mate	£0 10 0
Master	1 0 0

FOR VOLUNTARY EXAMINATION IN STEAM.

Mate (Only, or First)	£1 0 0
Master	1 0 0

FOR VOLUNTARY EXAMINATION IN DEVIATION OF THE COMPASS.

Mate (Second, Only, or First)	£1 0 0
Master	1 0 0

FOR "PLEASURE YACHTS."

Master	£2 0 0

NOTE.—No abatement will be made in the fee charged to a Candidate for a Certificate for Foreign-going Ships in consequence of his possessing a Master's or Mate's Certificate for Home Trade Passenger Ships.

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* If the examination for the Extra Master's Certificate takes place at the same time as the examination for the Ordinary Master's Certificate the usual fee for the Ordinary Certificate must be paid, though no fee will be charged for the Extra Examination on the first attempt. On all subsequent attempts the fee of one pound will be charged for the Extra Examination in addition to any further charge which may have been incurred through failure to pass the Ordinary Examination.

COLONIAL CERTIFICATES, &c.

78. Under section 8 of the "Merchant Shipping (Colonial) Act, 1869," and subject to certain conditions, Her Majesty may, by Order in Council, authorise the Governments of British Possessions to grant Certificates of *Competency*, which shall be of the same force as Certificates of Competency granted by the Board of Trade.

79. This advantage has already been extended to certain of the Certificates granted by the Governments of the following British Possessions, viz.:—

Victoria.
Canada.
New Zealand.
New South Wales.
Malta.
South Australia.
Tasmania.
Bengal.
Newfoundland.
Bombay.
Queensland.

80. The holder of an Ordinary Colonial Certificate, *i.e.*, a Certificate for Foreign-going Ships, not granted under the "Merchant Shipping (Colonial) Act, 1869," desirous of being examined for an imperial Certificate of the same grade, must prove that he has performed the amount of service required by the Regulations to entitle him to hold such a Certificate. He must also produce satisfactory testimonials as to character for at least the 12 months immediately preceding his application to be examined.

81. No fee will be demanded for the first attempt. If, however, the Candidate fails to pass his examination the usual fee should be demanded on any subsequent attempt.

82. Persons who hold Certificates of Competency obtained after an examination passed on board one of Her Majesty's Ships can also be examined without paying any fee the first time.

GENERAL INSTRUCTIONS TO EXAMINERS AND CANDIDATES.

83. Before commencing the examination, the tables or desks must be cleared of all scraps of paper, or books that are not used in the examination, and care should be taken that the Candidates do not bring into the examination room any book, paper, document, or memoranda of any description whatever. No person whatever should be allowed in the room during the time of examination but those whose duties require them to be present.

84. No instructors will be allowed on the premises.

85. Candidates will under no pretence whatever be allowed to leave the premises while the examination is proceeding. If they have occasion to visit the retiring room they will be required to enter in a book, kept for the purpose, the exact times of their leaving and returning to the examination room. At ports where only a few Candidates are under examination, two persons will not be allowed to leave the room at the same time.

86. Candidates should be so placed as to prevent one copying from the other, and no communication whatever between the Candidates should be allowed.

87. If any blotting paper is allowed it should be black; and when the first examination paper is issued, each Candidate should be furnished with a piece which must be returned to the Examiner upon the completion of the last paper.

88. The examination papers should be issued to the Candidates in half sheets only, and one at a time. This will prevent a Candidate from spreading out the sheets on the table in an apparently careless manner, but so as to enable his nearest neighbour to look over and copy, or examine the problems. It will also enable the Examiner to look over and report upon the work on one half sheet, while the Candidate is at work upon another, and so on. When the errors are not too numerous, or when they are not from ignorance of the subject, the incorrect problems may be returned to the Candidate for correction, but in no case should the errors be pointed out by the Examiner, neither should any marks be made on the correct work of the problem, which would at once indicate how far or to what extent the work is correct. Should the problems be returned to the Examiner the second time incorrect, this would be a failure; and as the time allowed is considered ample for working out the papers carefully, this rule is expected to be strictly observed.

89. At those ports where, from the large number of the Candidates, it may sometimes be found impossible to look over the work on the day of examination during the office hours, an hour in the morning of the following day may be allotted for the purpose of correcting the problems, but in no case should a Candidate have his problem returned to him for correction after he has made the second attempt.

90. The paper (Exn. 4 A.) is only for those candidates who present themselves for examination for the first time. It is intended not only to ensure on the part of the Candidate a knowledge of the meaning of a variety of terms of great use to the Navigator, respecting which much ignorance exists at present, but, at the same time, to test his handwriting and spelling.

91. In using this paper, the Examiner will place a mark against the numbers of the particular questions which he selects for answers, and not less than ten questions should be selected. The Candidate will then write against the questions so marked his definition of the terms, in a clear and legible hand, so as to prevent the possibility of any letter being mistaken. Attention should be paid to the spelling and writing of Candidates.

92. In the questions on Deviation of the Compass the Examiner should indicate by a mark against at least twelve of the questions for answers, and those indicated must be correctly answered. The selected questions should be varied frequently, and no two Candidates should have precisely the same questions. The Candidate should be furnished with sheets of blank ruled paper with instructions that he is to write only on one side of the paper, and to answer each of the questions against which a mark is placed, in a clear and legible hand, and to commence each answer by writing down the number of the question to which it relates on the side, where a margin should always be left for that purpose. In answering Question 19, besides giving a full explanation in writing the Candidates should be required to illustrate by diagrams how the poles of the magnets are placed with regard to the compass needle for correcting the semicircular deviation, as well as the heeling error, and also how the soft iron should be placed for correcting the quadrantal deviation. A Candidate for an Extra Master's Certificate will not be required to answer these questions, but will be examined by the Syllabus.

93. In the *viva voce* examination, a reasonable time should be allowed for the candidate to give his answers. No assistance should be given or leading question put.

94. Particular attention should be paid to the adjustments of the Sextant, and the written answers should be given on the ruled paper in the same manner as the answers to the questions on Exn. 7. Every candidate should have a practical knowledge of what is known as the first three adjustments, and be able to read correctly off the arc, a supposed index error to be given by the Examiner as additive, as well as reading off the arc in the usual way.

95. All outstanding or minor corrections should appear in the margin of each problem paper; also on the chart papers Exn. 9 C and Exn. 9 D, and unless all these corrections appear on the papers of the Candidate they will not be considered complete.

96. In every case the Examination, whether for Only Mate, First Mate, Master, or Master Extra, is to commence with the problems for Second Mate.

97. Examiners should bear in mind that the problems to be performed are required as tests, and for the purposes of an Examination, and not for sea-going or practical purposes alone.

98. The Candidates will be allowed to work out the various problems according to the method and the tables they have been accustomed to use.

99. The rules as to the amount of time allowed are as follow:—

100. *Candidates for Second Mates' Certificates of Competency* must complete the whole of their Examination in Navigation in *eight hours*, including the time allowed for writing the definitions (Exn. 4*a*), the paper on the adjustments of the sextant, and the correction of *all* errors and oversights; but the nautical problems on Forms "Exn. 4" and "Exn. 5" must be completed within *six hours*, and without the Candidates leaving the premises during that period.

101. *Candidates for Only and First Mates' Certificates* must complete the whole of their Examination in Navigation in *eleven and a half hours,** including the time allowed for the papers on the adjustment of the sextant, and the chart, and for the correction of *all* errors and oversights; but the nautical problems on Forms "Exn. 4," "Exn. 5," and "Exn. 6," must be completed within *six hours*, and without the Candidates leaving the premises during that period.

102. *Candidates for Masters' Certificates* must complete the whole of their Examination in navigation in *fourteen hours*, including the time allowed for the papers on the sextant, the chart, and the compass deviation, and for the correction of *all* errors and oversights; but the problems on Forms "Exn. 4," Exn. 5," and "Exn. 6" must be completed within *six hours*, and without the Candidates leaving the premises during that period.

103. *Candidates after finishing the problems required of their respective grades* on the first day of Examination, should proceed, until the end of that day, with such subjects as the definitions, sextant, chart, and Question 19 of Form "Exn. 7."

104. *The Sumner Problem (Exn. 6a)* must on no account be given out to any of the grades on the first day of the Examination, but should be the commencement of the Candidate's work on the second day, and on completion of this problem the Candidates for Masters' Certificates should proceed with the problems on Paper "Exn. 7."

105. *Candidates for Home Trade Mates' Certificates* must complete the whole of their arithmetic and chart papers within *five hours*, and Candidates for Home Trade Masters' Certificates within *six hours*.

106. *Candidates for Foreign-going Steamship Certificates of Competency* will be allowed the same amount of time to perform their navigation, &c., as herein-before laid down for the respective grades for the Ordinary Foreign-going Certificates.

107. Punctually at the expiration of the prescribed time all the papers should be called up, whether completed or not, and if not completed, the candidate will be declared to have failed, unless the Local Marine Board or the Examiner see fit to lengthen the period in any special case. If, however, the period is lengthened in any case, the special circumstances of that case, and the reasons for lengthening the period, together with the time allowed, must be reported to the Board of Trade by the Examiners, in the column for "remarks" on the Form Exn. 14.

108. It is anticipated that but few of the Candidates for Certificates of Competency for any of the foregoing grades will require the whole of the time herein allowed for completing their Examination in Navigation; and ample time has been prescribed, so that Candidates may perform their work in a careful, clear, and legible manner, and to the entire satisfaction of the Examiners.

109. If the Candidate passes he will receive the Form Exn. 16, which authorises the Superintendent of the Mercantile Marine Office to which it is addressed by the Examiner to issue the Certificate to the Candidate, whose testimonials, &c., will be returned at the same time. It is therefore important that the port of destination of the Certificate should be the same on both the Form Exn. 16 and the Form Exn. 2. If circumstances should make any alteration necessary, the Examiner should see that it is made in both Forms, otherwise delay in the issue of the Certificate may be caused.

SPECIAL NOTICE TO CANDIDATES.

110. The attention of Candidates is specially called to the following Regulations:—

111. Candidates are required to appear at the examination room punctually at the time appointed.

112. Candidates are prohibited from bringing into the examination room books, paper, or memoranda of any kind whatever. The slightest infringement of this regulation will subject the offender to all the penalties of a failure, and he will not be allowed to present himself for re-examination for a period of three months.

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* A Candidate other than Second Mate who may not previously have passed an examination may be allowed the time occupied in writing his definitions on Exn. 4*a*, in addition to the above.

113. In the event of any Candidate being detected in defacing, blotting, writing in, or otherwise injuring any book or books belonging to the Board, the papers of such Candidate will be detained until the book or books so defaced be replaced by him. He will not, however, be at liberty to remove the damaged book, which will still remain the property of the Board.

114. In the event of any Candidate being discovered referring to any book or memoranda, copying from another, or affording any assistance or giving any information to another, or communicating in any way with another, during the time of examination, he will subject himself to all the penalties of a failure, and he will not be allowed to be examined for a period of six months.

115. No Candidate will be allowed to work out his problems on a slate or on waste paper.

116. No Candidate will be permitted to leave the room until he has given up the paper on which he is engaged.

117. Candidates will find it more convenient, both here and at sea, to correct the declination and other elements from the Nautical Almanac by the "hourly differences" which have been given in that work in order to facilitate such calculations; they will thereby render themselves independent of any proportional or logarithmic table for such purpose.

118. The corrections by inspection from tables given in some of the works on navigation will not be allowed (see Tables IX, XI, and XXI, in Norie's Epitome, &c.); every correction must appear on the papers of the Candidates.

119. Candidates are expected to work out their answers to all problems, except those referred to hereafter, to within, or not to exceed, a margin of one mile of *position* from a correct result, with the exception of the ship's position by "Sumner's method," where a margin of 2½ miles may be allowed.

120. In finding the longitude by chronometer the logarithms used in finding the hour-angle should be taken out for seconds of arc. Also accuracy should be observed in computing the Hour-angles for the projection by "Sumner's method."

121. In all other problems the logarithms to the nearest minute will be sufficiently correct for all grades except Extra Master, from whom a degree of precision will be required, both in the work and in the results, beyond that demanded from the inferior grades.

122. Any Candidate who may be guilty of insolence to the Examiner or of other misconduct will render himself liable to the postponement of his examination, or, if he has passed, to the detention of his Certificate for such period as the Board of Trade may direct.

123. For rules as to amount of time allowed to perform the work, *see* "General Instructions to Examiners and Candidates" on page 12.

MASTERS' AND MATES' VOLUNTARY EXAMINATIONS IN STEAM.

124. These examinations are limited to Masters and First or Only Mates who are possessed of or entitled to Certificates of Competency, and were provided for the purpose of giving them an opportunity of undergoing a voluntary examination as to their practical knowledge of the use and working of the steam engine. They are conducted on the premises, and under the superintendence of the Local Marine Boards, at such times as they may appoint for the purpose; and the Examiners are selected by the Board of Trade from the Engineer Surveyors appointed under the fourth part of "The Merchant Shipping Act, 1854."

125. Any Master or Mate desiring to be examined in Steam must deliver to the Superintendent of the Mercantile Marine Office a statement in writing to that effect, upon the Form of Application (Exn. 2) and the applicant's Certificate of Competency must be delivered to the Superintendent along with his statement. If he is about to pass an examination for a Certificate of Competency at the same time, the applications should be sent in together.

126. A fee of one pound must be paid by the applicant for the examination *in Steam*, and the Superintendent of the Mercantile Marine Office will thereupon inform him of the time and place at which he is to attend to be examined, and the examination will then and

there proceed in the same manner as the other examinations. If the applicant fails, and has given in his certificate, it will be at once returned to him.

127. If the applicant passes, the Report (Exn. 14) will be sent to the Board of Trade, and the Certificate of Competency with the Form (Exn. 2) to the Registrar-General of Seamen; the words "*Passed in Steam*" with the date and place of examination, will then be entered on the Certificate and its counterpart, and the Certificate will be sent to the Superintendent of the Mercantile Marine Office of the port named in the Application (Exn. 2) to be delivered to the applicant in the usual manner.

128. If the applicant fails he may not present himself for re-examination until the expiration of three months from the date of failure.

129. The examination is for the most part *viva voce*, and extends to a general knowledge of the practical use and working of the steam engine, and of the various valves, fittings, and pieces of machinery connected with it. Intricate theoretical questions on calculations of horse-power or areas of cylinders and valves, or any of the more difficult questions which appertain to steam engines and boilers, will not be asked. The examination will in fact be confined to what a Master of a Steam vessel may be called upon to perform in the case of the death, incapacity, or delinquency of the engineer.

130. Examiners are to be careful in their examinations to satisfy themselves that applicants really do know the names and uses of the various parts of engines and boilers, and their connecting pipes, valves, cocks, &c. Practical knowledge, as distinguished from theories, abstruse calculations, and book learning, is to be the test of the applicant's fitness to have his certificate indorsed.

131. The Examiner should arrange to conduct part of the examination in the engine room of a Steamship, unless from circumstances he finds it impossible to do so; and if an opportunity offer the applicant should be permitted, under the guidance of the Examiner, to start and stop the engine of some vessel which may have her steam up.

132. The Examiner in sending in his report of Examinations of Masters and Mates in steam, should state where the examination has been held.

133. Candidates will be required to give written answers to sixteen out of twenty questions taken from a book of Elementary Questions published for the Board of Trade.* These questions will be altered from time to time without notice. The twenty questions are not to be difficult, theoretical, or book questions, but are to be such as any man of ordinary capacity ought to answer who has any "*practical knowledge of the use and working of the steam-engine.*"

134. These questions with the Candidate's answers, should be sent to the Board of Trade, with the reports, after each examination.

135. These answers will also assist in enabling the Board to decide any question that may hereafter arise in cases where it is alleged that applicants have been improperly passed, or improperly rejected.

136. The Examiners will be careful that if any candidate refers to any book or paper or memorandum, or obtains information from another candidate, during the examination, he will be treated as having failed, will forfeit his fee, and will not be allowed to be re-examined for a period of three months.

137. The Examiners will report in case of failure, the nature of the question or questions that decided the failure, or the point in the management of the engine in which the candidate was deficient.

138. There is nothing in the regulations requiring that applicants for the voluntary examination shall have served on board Steam Ships; all that is required is that they shall have a "practical knowledge." Examiners will, of course, not fail to appreciate the fact, when passing applicants, that practical knowledge is best gained in the engine room; and the examination of an Officer who does not produce official evidence of service in Steam Ships, and of experience of engines, must necessarily be more searching than in the case of one who produces evidence of such service and experience.

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* For the Answers see "AINSLEY'S ENGINEER'S MANUAL."

ON LOGARITHMS.

1. **Logarithms** are numbers arranged in Tables for the purpose of facilitating arithmetical computations. They are adapted to the natural numbers, 1, 2, 3, ... in such a manner that by means of them

the operation of Multiplication is changed into that of Addition;
. . . Division . . . . Subtraction;
. . . Involution . . . . Multiplication;
. . . Evolution . . . . Division;[*]

2. Take any whole numbers, as 18, 813, 6489; the first consists of two, the second of three, and the third of four figures or *digits*. Again, in the mixed number 739·815, the whole number or integral part (739) consists of three *digits*.

3. By multiplying a number by itself, *one*, *two*, *three*, &c., times successively, we obtain the *second*, *third*, *fourth*, &c., powers of that number; hence, a *power of a number is the number arising from successive multiplication by itself.* Thus, $3 \times 3 = 9$ is the square or second power of 3; and $5 \times 5 \times 5 = 125$, the cube or third power of 5; and so on.

These operations are denoted by means of *Indices*, or small figures placed on the right of the numbers, a little above the line; thus, $2^2 = 2 \times 2 = 4$, $3^3 = 3 \times 3 \times 3 = 27$, and $2^5 = 2 \times 2 \times 2 \times 2 \times 2 = 32$, where the *Index* or *exponent* denotes the number of factors employed.

4. When there are series of numbers, such that each is found from the previous one by the addition or subtraction of the same number, they are said to be in arithmetical progression. 1, 3, 5, 7, 9, 11, &c., are in arithmetical or equi-different progression, since each number is found by adding 2 to the immediately preceding.

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[*] No proof can here be offered that numbers must exist possessing the properties under which we call them logarithms; neither can any account be here given of the methods of computing such logarithms. The reader will accept the statements that if such numbers exist, bearing the properties aforesaid, they are called logarithms. He must also accept the tables which are published, recording logarithms for the several numbers to which they profess to belong, though he cannot at present verify the computations of these several logarithms; and he will be informed how he may use these tables to effect with comparative ease many calculations which would otherwise be most laborious.

The truth is, though it requires for its demonstration higher algebra than this work presupposes the reader to be acquainted with, that not only has every number a logarithm, but it has an infinite variety of logarithms, constructed, as the term is, on different scales or bases. The base of any system of logarithms is defined by the fact that in that system *unity* is its logarithm.

Any number *might* be used as a base; but in fact there are only two numbers which are ever really used.

The one is an unterminating decimal, 2·7182818 . . . ., denoted generally by the letter *e*. This is the base of what is called the natural or Naperian system; and the advantage of it consists in the ease with which logs. are computed to this base, but which we cannot here explain.

The other is 10, which is the base in ordinary use, and with this base log. 10 = 1. Logarithms to this base are the only ones which will now be considered in their practical use.

5. Again, the numbers 3, 6, 12, 24, &c., are in geometrical progression, for each number is formed from the one immediately preceding by multiplying by 2. If we take the following series of powers, 3^1, 3^2, 3^3, 3^4, 3^5, &c., we find that the exponents proceed in arithmetical progression, and the quantities themselves in geometrical progression.

6. **Def.**—Logarithms are a series of numbers in *arithmetical* progression answering to another series in *geometrical* progression, so taken that 0 in the former corresponds with 1 in the latter.

Thus, 0, 1, 2, 3, 4, 5, 6, &c., are the logarithms or *arithmetical* series,
and 1, 2, 4, 8, 16, 32, 64, &c., are the numbers or geometrical series,
answering thereto—the latter being called the *natural number*.
Or, 0, 1, 2, 3, 4, 5, the logarithms,
and 1, 5, 25, 125, 425, 5125, the corresponding numbers.
Or, 0, 1, 2, 3, 4, 5, the logarithms,
and 1, 10, 100, 1000, 10000, 100000, the corresponding numbers.

In which it will be seen, that by altering the common ratio of the geometrical series, the same arithmetical series may be made to serve as logarithms of any series of numbers. As above, when the common ratio of the geometrical series are 2, 5, and 10 respectively.

7. The common ratio in the geometrical series corresponding to the common difference of 1 in the arithmetical series is called the **base** of the system. Thus, the base of the first specimen exhibited is 2, the base of the second is 5, and the base of the third is 10.

In the specimens just exhibited we have, in each, taken two ascending progressions, but they might equally well have been two descending progressions, or the one descending and the other ascending. Logarithms, however, as now used in practice, are limited to the case of two progressions, either both ascending or both descending—the former giving the logarithms of integers, the latter of fractional numbers.

But a better way of considering logarithms is as follows:—

8. **Def.**—The logarithm of a number to a given base is the index of the power to which the base must be raised to give the number.

For instance, if the base of a system of logarithms be 2, 3 is the logarithm of 8, because $8 = 2^3 = 2 \times 2 \times 2$.

And if the base be 5, then 3 is the logarithm of the number 125, because $125 = 5^3 = 5 \times 5 \times 5$.

There may be thus as many different systems of logs. as we please; but, for practical use, it is necessary to select and adhere to one. That usually employed now is called *Briggs' system*.

9. We now proceed to describe what is called the **common system of logarithms.** In the common system of logarithms unity is assumed to be the logarithm of 10; that is, 10 is the constant base. All the logarithms registered in the Tables commonly used, are indices of the radix or base 10; a Table of logarithms of numbers is in fact nothing more than a Table of the exponents of 10 placed against the several numbers themselves. Accordingly—

0	is the log. of	1,	because	$1 = 10^0$
1	,,	10,	,,	$10 = 10^1$
2	,,	100,	,,	$100 = 10^2$
3	,,	1000,	,,	$1000 = 10^3$
4	,,	10000,	,,	$10000 = 10^4$
	&c.		&c.	

Now, if the above Tables were amplified by the insertion of the logarithms of all the numbers between 1 and 10, between 10 and 100, &c., we should have a Table of logarithms of all numbers from 1 to 10000; and whatever may be the difficulty of determining the intermediate logarithms, it is at once easily seen that the logarithms of all numbers between 1 and 10, *i.e.*, between 10^0 and 10^1 must lie between 0 and 1, and will be 0 + a fraction, that is, a decimal less than 1; of all numbers between 10 and 100, *i.e.*, between 10^1 and 10^2 must lie between 1 and 2, and will be 1 + a fraction, or a decimal between 1 and 2; of all between 100 and 1000 will be 2 + a fraction, and so forth; or the integral part of each intermediate logarithm will be *one less* than the number of integral figures in the quantity of which it is the logarithm. Thus, the logarithms of 2, 3, 4, &c., to 9, have 0 as the integral part; those of 10, 11, 12, &c., to 99 have 1 as the integer; those of 100, 101, 102, &c., to 999, have 2 as the integer; and so forth. Hence Tables of logarithms usually supply only the fractional or decimal part; the integral part is always known from the number of integers in the value whose logarithm is wanted. Very few logs. can be expressed in terminating decimals, but this causes little inconvenience, since a log. carried to six or seven decimal places is sufficiently exact for all common purposes.

10. The integers 1, 2, 3, 4, &c., which are the logarithms of 10 and its powers (see 9), are chief indices, and the logarithms intermediate to these, as for instance 1·778151 (which is the logarithm of 60) consisting of an integer and a decimal fraction, though they are also indices, are usually referred to as consisting of an *index*[*] and *mantissa*[†], the integral part being specially termed the *index* or *characteristic*, because it indicates, by being *one less*, how many integral places are in the corresponding natural number, and the annexed decimal being called the *mantissa*.

Example.—In the log. 4·616339, the figure (4) standing to the left of the decimal point is the *characteristic* or *index*, and the remaining portion (·616339) is the *mantissa* or *decimal part*.

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[*] In order to avoid confusion from the use of the word "index" to signify two things, we shall throughout this work employ the term *characteristic* when speaking of logarithms, and *index* when speaking of roots or powers.

[†] *Mantissa*, a Latin word signifying an additional handful; something over and above an exact quantity.

11. To find the characteristic of the logarithm of any number greater than unity we have, therefore, the following rule:—

RULE I.

The characteristic of the logarithm of a number greater than unity, i.e., *of a* whole *or* mixed number, *is* one less *than the* number of the digits *of its integer part*

Thus: the characteristic of the logarithm of 849 is 2; for the number 849 is an integer consisting of three digits (that is the number between 100 and 1000) and 1 less than 3 is 2. Also, the index of the log. of 264·96 (which is a mixed number) is 2, since the integral part of the number, namely 264, is a number between 100 and 1000, or consists of 3 digits, and one less than 4 is 3. Again, 3 is the characteristic of the logarithm of 3847·216, since this number has 4 integral digits; while 0 is the characteristic of the logarithm of 3·847216, since this number has one integral digit.

Again, the characteristic of the log. of a number of *one* place of integers (such as 5 or 5·08, or 5·0801) is 0. Again, every number with *two* places of integers (such as 50, or 50·8, or 50·813) is 1. Again, every number with *three* places of integers (such as 508, or 508·2, or 508·25) has for its characteristic 2, and so on.

EXAMPLES FOR PRACTICE.

Write down the characteristics of the logarithm of the following numbers:—

1. 365
2. 4·8
3. 643·75
4. 28·9
5. 6
6. 69710
7. 45·82
8. 8640
9. 75
10. 7·265
11. 474000
12. 4256·45
13. 3·9
14. 8
15. 18
16. 473·908
17. 54793000
18. 21256·8
19. 2·14006
20. 50·7406

12. It has been shown that in the common system of logarithms (Brigge') the log. of 1 is 0; consequently, if we wish to extend the application of logs. to fractions, we must establish a convention by which the logs. of numbers wholly decimal, *i.e.*, less than unity, may be represented by numbers less than zero, *i.e.*, by *negative numbers*.

Extending, therefore, the above principles to negative exponents, since

$$\begin{array}{llll}
10^{0} = & 1 & = 1 & 0 \\
10^{-1} = & \frac{1}{10} & = 0·1 & \bar{1} \text{ is the logarithm of } ·1 \text{ in this system.} \\
10^{-2} = & \frac{1}{100} & = 0·01 & \bar{2} \quad \text{,,} \quad ·01 \quad \text{,,} \\
10^{-3} = & \frac{1}{1000} & = 0·001 & \bar{3} \quad \text{,,} \quad ·001 \quad \text{,,} \\
10^{-4} = & \frac{1}{10000} & = 0·0001 & \bar{4} \quad \text{,,} \quad ·0001 \quad \text{,,} \\
\quad \&c. & & & \&c.
\end{array}$$

It follows from this, that when the number is a decimal with all its digits significant, in value between 1 and $\frac{1}{10}$, its log. is negative, yet not so small as the log. of $\frac{1}{10}$, which is — 1. Its log. therefore will be something between 0 and — ·1, or — 1 with some positive decimal added. Hence — 1 is its characteristic. When the number is a decimal with zero as its first digit, in value therefore below $\frac{1}{10}$ but not so low as $\frac{1}{100}$, its log. is less than — 1, but not so small as —2, and so will be —2 with some positive decimal attached. Thus $\bar{2}$ is the characteristic. The log. of a decimal between ·01 and ·001 is some number between —2 and —3, and its characteristic is —3; of a number between ·001 and ·0001 its log. is between —3 and —4, and its characteristic is —4; and generally, following this reasoning, it will appear that the characteristic of a decimal fraction is negative, and may be known from its denoting the place of the first significant figure of the decimal, as being the 1st, 2nd, 3rd, &c., place after the point; hence,

13. To find the characteristic of any number less than unity, *i.e.*, of a decimal, we have the following

RULE II.

The characteristic of the logarithm of a number less than unity, and reduced to the decimal form, is negative and one more than the number of cyphers following the decimal point.

A negative characteristic is denoted by writing over it the negative sign (—), thus $\bar{1}$, $\bar{2}$, $\bar{3}$, &c.*

Thus the chatacteristic of the logarithm of ·00521 is $\bar{3}$, since the number of cyphers following the decimal point increased by 1 is 3.

Similarly the index of log. of ·156 is $\bar{1}$
" " ·0·56 is $\bar{2}$
" " ·00046 is $\bar{4}$
" " ·000000721 is $\bar{7}$

14. But in order to avoid the confusion that might arise by the addition and subtraction of *negative* indices, the following rule is frequently used.

RULE III.

Add 1 *to the number of cyphers between the decimal point and the first significant figure, and subtract from* 10; *the remainder is the index required.*

Thus the characteristic of the log. of ·04 is $\bar{2}$, or 8, since 1 added to the number of cyphers following the decimal point is 2, then 2 from 10 is 8.

Similarly the index of log. of ·140 is 9.
" " ·0149 is 8.
" " ·00064 is 6.
" " ·000000721 is 3.

(a) If the characteristic of a vulgar fraction is required, it must first be reduced to an equivalent decimal fraction, and then the index is found by the rule.

Thus, the index of log. $\frac{1}{8}$, or of log. ·125 is $\bar{1}$ or 9.
" of log. $\frac{1}{25}$, or of log. ·04 is $\bar{2}$ or 8.
" of log. $24\frac{2}{5}$, or 24·4 1.

EXAMPLES FOR PRACTICE.

Write down the characteristics of the logarithms of the following decimal fractions:—

1. ·045
2. ·9
3. ·0004
4. ·6798
5. ·0062
6. ·0000001
7. ·01
8. ·0003127
9. ·02803
10. ·7007
11. ·4537
12. ·009
13. ·0000008
14. ·000064
15. ·000485
16. ·037299
17. ·00000052018
18. ·000000205379
19. ·5
20. ·00000000000382

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* The negative sign (—) is written *above* the characteristic, thus $\bar{2}$, instead of before it, to show that it affects only the characteristic and not the mantissa, which remains positive. If it were written in front of the complete logarithm it would signify that the entire logarithm was negative, but such logarithms are never employed in the operations connected with navigation.

15. The characteristic may also be found as follows:—

RULE IV.

Place your pen between the first and second figure, (not cypher), *and count one for each figure or cypher, until you come to the decimal point; the number thus given will be the characteristic: but observe that if you count to the* left *you must* subtract *the number found from* 10, *and consider the* remainder *as the characteristic.*

Thus, in finding the log. of 4·6017, if you place the pen between the first figure (4) and second (6), it falls on the decimal point; in this case the characteristic is 0. Next, in the case of log. of 4601·7, place your pen between 4 and 6, and count $\begin{array}{l|l}4 & 601\cdot7\\ & 123\end{array}$; the characteristic is 3. Next, in the case 4601700, here the decimal point falls behind the last cypher (No. 5). Hence, counting as before, we have $\begin{array}{l|l}4 & 601700\\ & 123456\end{array}$ and the characteristic is 6.

Again, in the case of log. ·00046017 the first significant figure is 4. Hence, counting, we have $\begin{array}{r|l}\cdot0 & 0046017\\ 4 & 321\end{array}$, but here we count to the left, so that the characteristic is negative, or $\bar{4}$, which taken from 10 is 6. Again, in the case of log. of ·46017, we have $\begin{array}{r|l}\cdot4 & 6017\\ 1 & \end{array}$, and the characteristic is $\bar{1}$, or 9.

16. The mantissa of the logarithm depends entirely on the relative value of the figures composing the quantity whose logarithm it is, and not at all upon the *numerical* value of that quantity: thus, the mantissa of the log. of 13 is ·113943, which is also the mantissa of 1·3, or 130, or 1300, for in each case the 1 and the 3 have the same relative value. So the mantissa of a logarithm is always the same, if the significant figures remain the same, and is not altered by the addition of cyphers to the right or left of these figures, or what is equivalent, by the multiplication or division of the quantity by 10, or any power of 10; it is only the characteristic which alters its value by an alteration in the position of the decimal point, 1 being added to the characteristic for every place the decimal point is removed to the right, that is, for every 10 by which the quantity is *multiplied;* or, 1 is *subtracted* from the characteristic for every place the decimal point is removed to the left, that is, divided by 10.

The logarithm of	745800	being	5·872622
that of	74580	is	4·872622
,,	7458	,,	3·872622
,,	745·8	,,	2·872622
,,	74·58	,,	1·872622
,,	7·458	,,	0·872622
,,	·7458	,,	$\bar{1}$·872622
			or 9·872622
,,	·07458	,,	$\bar{2}$·872622
			or 8·872622
,,	·007458	,,	$\bar{3}$·872622
			or 7·872622
,,	·0007458	,,	$\bar{4}$·872622
			or 6·872622

ON TABLES OF LOGARITHMS OF NUMBERS.

17. In RAPER'S, NORIE'S, and the collection of nautical tables intended to accompany this work, the Tables of the Logarithms of Numbers are arranged so as to give the mantissæ of the natural numbers from 1 to 10000. If the reader will open an ordinary table of logarithms, such as is contained in the above-mentioned works, he will find a short table of logs. from 1 to 100 immediately preceding the general table, and giving the entire logarithm; following which is the general table, on opening which he will find a vertical column on the left side of the page containing three digits and ten columns of logarithms headed by the digits 0, 1, 2, ... 9. These last are fourth digits to be attached to the former three, so that the table thus embraces numbers from 1000 up to 9999. Opposite to every such number is a number with six places of figures. This is a decimal, though to save printing the decimal point is not printed, and it is the decimal part, or mantissa, of the logarithm of the number to which it corresponds. The characteristics are never printed, but are prefixed according to the Rules I, II, and II. Hence from such a table we can take out the logarithm of any number with any four significant digits.

In the margin of all tables of logarithms the difference of the successive logarithms in that part of the table is set down. In some tables, also, there are little tables in the margin called *tables of proportional parts*. These are placed under every successive difference, and contains for that difference the number to be added in respect of each unit's digit, so as to form the logarithm of numbers of six digits. These numbers are found as directed by the Rule VIII, page 25.

18. If the number be given, its logarithm may be found as follows:—

To find the logarithm of a number consisting of not more than two digits, *i.e.*, which does not exceed 100, using the short table of logarithms, from 1 to 100, preceding the general table.

RULE V.

Seek for the number proposed, considered as a whole number, in the column at the top of which is No., *and the logarithm will be found opposite to it in the next column to the right hand.* Prefix the proper characteristic (by changing it if necessary) to the mantissa (see Rules I and II, pages 20 and 21). The result is the logarithm sought.

NOTE.—It may be observed here, once for all, that the proposed number must be considered a whole number, and in case a decimal point occurs in the given number, no notice is taken of it till we come to the insertion of the characteristic; and should cyphers occur *between the decimal point and the first significant figure*, these, also, are disregarded in entering the table, being only taken into account when determining the characteristic.

Ex. 1. Required the logarithm of 21, 2·1, ·21, and ·021.

In the first page of the Table, and in one of the vertical columns marked *No.*, we find 21, against which stands 1·322219, the logarithm sought. Since the mantissa of the logarithm of any number consisting of the same figures is the same whether the number be integral, fractional, or mixed, the logarithms of the numbers 2·1, ·21, and ·021 will have the same decimal part as 21, the characteristic only being changed, consequently the logarithm of 2·1 is 0·322219, the logarithm of ·21 is 9·322219, and the logarithm of ·021 is 8·322219.

Ex. 2. To find the logarithm of 52, 5·2, ·52, and ·00052:—

In the Tables we find the log. of 52 is 1·716003, and, therefore, simply changing the index, the log. of 5·2 is 0·716003, ·52 is 9·716003, and the log. of ·00052 is $\bar{4}$·6716003 or 6·716003.

No.	Nat. No.	No.	Nat. No.	No.	Nat. No.	No.	Nat. No.
1.	5	7.	41	13.	94	19.	·0091
2.	9	8.	·004	14.	½ or ·5	20.	25·0
3.	·009	9.	2·4	15.	¾ or ·75	21.	·024
4.	·01	10.	24	16.	2·5	22.	·000035
5.	·0001	11.	·24	17.	¼ or ·25	23.	·000057
6.	14	12.	·0021	18.	·09	24.	$\frac{1}{1000}$

19. To find the logarithm of a number consisting of not more than three places of figures (from 100 to 1000).

RULE VI.

Find the given number in the left-hand column of the Table, and opposite it, in the next column, will stand the mantissa or decimal part of the logarithm. Prefix the characteristic according to Rules I and II. The result is the logarithm sought.

Note.—When we say "three figures" we mean independently of cyphers either to the right or to the left. Thus we should include 6340, 73200, and ·00265 under the head of this problem.

Note.—*If the number is less than three figures* make up three by placing cyphers, if not already present (or by supposing them placed), on the right of the number, cyphers so added being regarded as decimal; then proceed as directed in the above Rule VI. Thus the logarithm of 75 is the same as that of 75·0; the logarithm of 8 is the same as of 8·00; and that of ·035 is the same as of ·0350.

Example.

Ex. 1. Required the log. of 476, 4·76, and ·00476.

We seek in the left-hand column of the Table for 476, against which in the column marked 0 at the top, stands the mantissa corresponding thereto; and this part by the rule is the same for each of the above numbers. Now prefixing the index according to the number of integral figures in the natural number, we find the log. of 476 is 2·677607; of 4·76 is 0·677607; and of ·00476 is 7·677607.

Again, the logarithm of 576 is 2·760422; that of 39·4 is 1·595496; that of ·0253 is $\bar{2}$·403121.

No.	Nat. No.	No.	Nat. No.	No.	Nat. No.	No.	Nat. No.
1.	100	5.	673	9.	8·96	13.	·0147
2.	145	6.	794	10.	1·47	14.	424
3.	2·94	7.	982	11.	·147	15.	·0000448
4.	361	8.	4·80	12.	·901	16.	448000

20. If the number contains four places of figures, exclusive of final cyphers, or cyphers included between the decimal point and the first significant figure.

RULE VII.

Find the first three figures in the vertical column on the left marked No., *and the fourth in the horizontal column at the top of the page. Under this last, and opposite* *the three figures, will be found the mantissa of the logarithm sought.* Prefix the index according to Rules I and II. The result is the logarithm sought.

EXAMPLE.

Ex. 1. Required the logarithms of 4587 and of 0·0004587.

The first three figures (viz., 458) being found in the column to the left marked No, and the fourth (7) in the line of digits at the top of the page, the decimal part of logarithm (·661529) is found in the same horizontal line as the three first figures of the given number, and in the same column as the fourth. The characteristic is 3, being one less than the number of *integers* in the whole number; whence the completed logarithm is 3·661529. The logarithm of ·0004587 is $\bar{4}$·661529, the characteristic being negative, and one more than the number of prefixed cyphers.

Again, the logarithm of 3470 is 3·541330; that of 3·492 is 0·543074; and that of 0·3468 is $\bar{1}$·540079; that of 74·39 is 1·871515; that of 325600 is 5·512648, in which case the mantissa of 3256 is taken out, since it is the same as the mantissa of 3256000.

No.	Nat. No.	No.	Nat. No.	No.	Nat. No.	No.	Nat. No.
1.	1000	4.	5432	7.	·01012	10.	987·6
2.	1234	5.	26·06	8.	94·87	11.	·06843
3.	25·65	6.	2·606	9.	7·777	12.	·002784

NOTE.—The foregoing rule may be used not only in the case of numbers consisting of four places of figures, but may be made to include all numbers consisting of less than four significant digits, and so enable us to dispense with the Rules V and VI. Thus, if the number consists of less than four figures, make up four by placing cyphers, if not already placed (or by supposing them placed), on the right of the number; cyphers so added being regarded as decimals. Then proceed to find the mantissa of the log. by the foregoing rule.

Thus, the log. 75 is the same as the log. of 75·00; the log. of 8 is the same as the log. of 8·000; and that of ·035 the same as that of ·03500 (3500 in the tables).

21. Although the tables in RAPER, NORIE, and the "Nautical Tables" accompanying this work are constructed so that the mantissæ corresponding to more than four figures cannot be taken out directly, yet the mantissæ of numbers containing five or six figures can be found from them without much trouble by means of the tabular difference taken out of the extreme right hand column of the page (see 86).

If the number consists of more than four figures other than final cyphers, or if the number be a decimal fraction, cyphers immediately following the decimal point, we use

RULE VIII.

1°. *Cut off the first four figures and consider the rest as a decimal.*

2°. *Find the mantissa corresponding to the first four figures* (Rule VII).

3°. *Multiply the tabular difference by the decimal cut off*, i.e., by the remaining figures of the given number, *and cut off from the right-hand as many figures as there are in the* multiplier, *but at the same time adding unity if the highest figure thus cut off* is not less than 5.

4°. *Add the integer part of this product to the figures of the mantissa just found.* These proportional parts are thus compiled on the supposition that the difference between *the numbers (nearly equal to each other) is proportional to* *the difference between their logarithms.* This proportion can be shown to be approximately true.

The result is the mantissa of the required logarithm.

The characteristic or index is found by Rules I and II, pages 20 and 21.

EXAMPLES.

Ex. 1. Required the logarithm of 28434.

$$\begin{array}{r} \text{Tab. diff.} \\ 153 \\ \times\ 4 \\ \hline 61{,}2 \text{ or } 61 \end{array} \qquad \begin{array}{rl} \text{Mantissa of } 2843 = & \cdot453777 \\ \text{Tab. diff. } 153 \times 4 = 61\cdot2 = & +\quad 61 \\ \text{Characteristic } = & 4 \\ \hline \text{The log. of } 28434 = & 4\cdot453838 \end{array}$$

We seek in the left-hand column of the Table for 284 (the first three digits) and also at the top of the page in one of the horizontal columns we find 3 (the fourth figure), then in a line with the former and in the column with the latter at the top we have 453777, which is the mantissa of 2843. In a line with the quantity in the right-hand column marked Diff., stands tab. diff. 153; which multiplied by 4, the remaining digit of the given number, produces 612; then cutting off one digit from this (since we have multiplied by only *one* digit) it becomes 61, which being added to 453777 (the mantissa of 2843) makes 453838, and, with the characteristic, 4·453838, the required logarithm.

The logarithm of 284·34 is 2·453838, and the log of ·028434 is $\bar{2}$·453838 or 8·453838.

Ex. 2. Required the logarithm of 12806.

$$\begin{array}{r} \text{Tab. diff.} \\ 338 \\ \times\ 6 \\ \hline 202{,}8 \text{ or } 203 \end{array} \qquad \begin{array}{rl} \text{Mantissa of } 1280 = & \cdot107210 \\ \text{Tab. diff. } 338 \times 6 = 202\cdot8 = & +\quad 203 \\ \text{Characteristic} = & 4 \\ \hline \text{The log. of } 12806 = & 4\cdot107413 \end{array}$$

Ex. 3. Find the logarithm of 873457.

$$\begin{array}{r} \text{Tab. diff.} \\ 50 \\ +\ 57 \\ \hline 28{,}50 \text{ or } 29 \end{array} \qquad \begin{array}{rl} \text{Mantissa of } 8734 = & \cdot941213 \\ \text{Tab. diff. } 50 \times 57 = 28\cdot50 = & +\quad 29 \\ \text{Characteristic} = & 5 \\ \hline \text{The log. of } 873457 = & 5\cdot941242 \end{array}$$

The mantissa of the first four figures is found thus;—Opposite the 873 and under 4 stands 941213; then in the right-hand column in a line with this stands the diff. 50, which being multiplied by 57, the remaining digits of the given number, makes 2580; from this we cut off *two* digits to the right (since we have multiplied by *two* digits), when it becomes 18; but as the highest digit cut off is 5, we add unity, which makes 29. Then 5·941212 (the logarithm of 8734) + 29 = 5·941242 is the required logarithm.

Ex. 4. Required the logarithm of 628007.

$$\begin{array}{rl} \text{Mantissa of } 6280 = & \cdot797960 \\ \text{Tab. diff. } 69 \times 07 = 4\cdot83 = & +\qquad 5 \\ \text{Characteristic} = & 5 \\ \hline \text{The log. of } 628007 = & 5\cdot797965 \end{array} \qquad \begin{array}{r} \text{Tab. diff.} \\ 69 \\ \times\ 07 \\ \hline 4{,}83 \text{ or } 5 \end{array}$$

The log. of 628·067 is 2·798006, and the log. of ·00628067 is $\bar{3}$·798006 or 7·798006. The mantissa of the log. of each of these numbers being the same, the index only being varied. (See Rules I and II).

1. 38475
2. 384·75
3. 12345
4. 543·21
5. 66666
6. 9244·8
7. 435·60
8. 78·604
9. 2·2055
10. 0·78362
11. 10000
12. ·000800073
13. 200000
14. ·056214
15. ·0098563
16. 643786
17. 1129·06
18. ·998095
19. 365152
20. 997·1370
21. 32·1908
22. 1·032764
23. $10001\frac{1}{25}$
24. 596·423

22. To find the natural number corresponding to a given logarithm.—If the logarithm be given, the number which corresponds to it may be found by the following rules, which are the converse of those last given for finding the logarithm when the number is given.

Since the characteristic denotes how many places the first significant figure stands to the right or left of the unit's place; conversely, therefore, if logs. be given having for characteristics 1, 2, 3, ... $\bar{1}$, $\bar{2}$, $\bar{3}$, ..., there are in the integral parts of the number to which these logs. belong, 2, 3, 4, ... 0, $\bar{1}$, $\bar{2}$, ... digits respectively. In illustration of these remarks take the following:—

Log. 4·589950	(in which characteristic 4)	gives 38900
3·589950	3	3890
2·589950	2	389
1·589950	1	38·9
0·589950	0	3·89
$\bar{1}$·589950 or 9·589950	$\bar{1}$ or 9	·389
$\bar{2}$·589950 or 8·589950	$\bar{2}$ or 8	·0389
&c.	&c.	

In which it will be observed that the first answer must consist of five integers, because the index of the given logarithm is 4; that the second answer must contain four integers, because the index of the given logarithm is 3; that the third answer must contain three integers, because the index of the logarithm is 2, &c., &c.; and that the sixth answer must be a decimal fraction having the first significant figure in the place of tenths, because the logarithmic index is $\bar{1}$; and lastly, that the seventh answer must be a decimal fraction having the first significant figure in the place of hundredths, because the logarithmic index is $\bar{2}$.

23. From the foregoing it is evident that when the figures of the natural number have been found, we must place the decimal point so that the number of integral figures may be one more than the characteristic denotes. Cyphers must be supplied to the right, if necessary, to make up the number, hence

RULE IX.

Add 1 *to the characteristic of the given logarithm, and mark off to the left the number of figures for whole numbers; the rest (if any) will be decimals.*

If the characteristic is negative place the decimal point to the left of the natural number found, along with as many cyphers as may remove the first significant figure to that place of decimals which the index expresses; that is, one cypher fewer than the number denoted by the characteristic, whence, to find the place of the decimal, we have the following

RULE X

The number corresponding to a logarithm with a negative index is wholly decimal, and the number of cyphers following the decimal point is one less than the characteristic of the logarithm.

But instead of the negative characteristic its *arithmetical* complement is sometimes used, in which case we proceed by

RULE XI.

Add 1 *to the index, and subtract the number thus found from* 10; *the remainder is the number of cyphers to be prefixed to the figures taken out of the Tables. Place the dot before the first cypher.*

24. To find the natural number corresponding to any given logarithm.

When the mantissa or decimal part of the logarithm can be found exactly in the Table, we proceed by

RULE XII.

1°. *Seek out the mantissa, and take from the column* No. *the three figures in the same horizontal row.*

2°. *From the head of the column take the fourth figure.*

3°. *From the characteristic find by the rules already given the position of the decimal point,* and so adjust the local value of the figures. (Rules IX, X, and XI, No. 23, page 27).

(*a*) *When the* characteristic *of the given logarithm requires a* greater number of digits *to the* left *of the* decimal point *than there are in the number found by the above rule, the* deficiency *is made up by* adding *a sufficient number of cyphers to the right.*

(*b*) *If the* natural number *is a* decimal fraction, *and the final figure or figures are* cyphers, *they need not be written down.*

EXAMPLES.

Ex. 1. Given the logarithm 2·698970, to find the natural number.

Entering the Table with the decimal part ·698970, we find the natural number corresponding to it to be 5, or 50, or 500, or 5000, &c., but as the index of the logarithm is 2, the natural number must contain three integral figures. Hence the natural number of 2·698970 is 500.

Ex. 2. Given the logarithm $\bar{3}$·539954 or 7·539954: find the number.

Entering the Table with the decimal part, we find the corresponding number is 3467; to this we prefix two cyphers, since the index is 3; or adding 1 to 7 (8), and subtract 8 from 10, we have 2, the number of cyphers to be prefixed, and then the decimal point; hence the number corresponding to 7·539954 is ·0034567.

Ex. 3. What number corresponds to the logarithm 4·214314.

The decimal part of the log. being found opposite 163 and under the figure 8 at the top of the page: therefore the digits of the required number are 1638. But as the characteristic is 4, there must be in it 5 places of integers. A cypher is annexed (see Rule XII, (*a*). Hence the required number is 16380.

Ex. 4. Required the natural numbers corresponding to logs. 0·176091 and $\bar{4}$·176091.

(1) The mantissa ·176091 stands in the Table opposite 150, and the column with 0 at the top; and the characteristic 0 shows that one of these is integral, whence the number sought is 1·500 or 1·5 (see Rule IX, page 27).

(2) The mantissa of second log. being the same as that of the first, the corresponding number will consist of the same significant figures, but the characteristic $\bar{4}$ shows that the first significant figure (1) must occupy the fourth place to the right of the decimal point, whence the number sought is ·00015. (See Rule X or XI, pages 27 and 28).

Ex. 5. Required the natural number whose logarithms are respectively 1·813514, 0·303412, 4·996993, $\bar{2}$·299943 or 8·299943, 4·000000, $\bar{4}$·000000, 7·816109, we shall find them to be as follows:—

1·813514 = log. of 65·09
·303412 = „ 2·011
4·996993 = „ 99310
$\bar{2}$·299943 or 8·299943 } = „ ·01995
4·000000 = „ 10000
$\bar{4}$·000000 = „ ·0001
7·816109 = „ 65480000

Where it will be observed that the first answer must contain only two integers, as the index of the given logarithm is 1; that the second must contain only one integer as the characteristic is 0; that the third must consist of five integers, because the index of the given logarithm is 4, and therefore to 9931, the number found in the Table, a cypher is annexed, (see Rule XII, (*a*); and that the fourth answer must be a decimal, having the first significant figure two places to the right of the decimal point because the characteristic is $\bar{2}$; the fifth answer must consist of five integral figures (a cypher being annexed to make up the number) since the characteristic is 4; the mantissa of the sixth log., or ·000000, gives the corresponding natural number 1000, but adjusting the decimal punctuation, or the local value of the figures, the characteristic $\bar{4}$ denotes that the first significant figure (1) must stand in the fourth decimal place, and, therefore, three cyphers must be prefixed, and the natural number will be ·0001—the three final cyphers not being written down. Finally, the mantissa of last log. being found in the table gives the natural number corresponding as 6548, to which annex four cyphers; the characteristic 7 determines the number to consist of 8 integral figures.

No.	Log.	No.	Log.	No.	Log.	No.	Log.
1.	0·477121	9.	3·898506	17.	2·990561	25.	$\bar{7}$·991093
2.	0·041393	10.	2·538574	18.	4·541579	26.	7·903524
3.	0·973128	11.	2·394977	19.	$\bar{1}$·744058	27.	$\bar{2}$·621488
4.	1·161368	12.	3·845098	20.	$\bar{1}$·501196	28.	$\bar{9}$·901349
5.	0·812245	13.	7·000000	21.	$\bar{7}$·875061	29.	$\bar{3}$·662758
6.	2·767898	14.	5·825426	22.	6·602060	30.	$\bar{4}$·851258
7.	0·394452	15.	4·698970	23.	$\bar{8}$·845098	31.	6·913761
8.	1·478422	16.	5·000000	24.	3·605197	32.	5·868527

25. When, as usually happens, the mantissa cannot be found exactly in the Tables, but lies between two successive records in the Tables, and it is proposed to find the corresponding number correct to six places of figures, other than final cyphers immediately following a decimal point, the number is to be found by the method of proportional parts, on the supposition that, between two successive records in the table, the number advances in proportion to the increase of the logarithm.

26. To find the natural number corresponding to a given logarithm, when more than four figures are required. We proceed by

RULE XIII.

1°. *Having found the next lower mantissa in the Tables, note the four figures which correspond to it.*

2°. *From the given logarithm subtract that taken out of the Tables, divide the remainder (annexing as many cyphers as there are digits required above four) by the tabular difference, and reduce the quotient to the form of a decimal.*

No.	Log.	No.	Log.	No.	Log.	No.	Log.
1.	2·931214	7.	5·734968	13.	5·831835	19.	$\bar{2}$·241877
2.	3·625343	8.	5·823904	14.	4·841989	20.	6·371000
3.	4·851906	9.	4·994603	15.	4·092561	21.	$\bar{6}$·246631
4.	4·361730	10.	4·925936	16.	1·217845	22.	$\bar{1}$·998813
5.	1·725364	11.	5·091512	17.	$\bar{3}$·984671	23.	$\bar{4}$·932847
6.	1·972521	12.	2·535224	18.	$\bar{4}$·463726	24.	$\bar{5}$·565942

27. **Def.**—The arithmetical complement of a number is the number by which it falls short of the units of the next higher denominator. (If x is any number whatever, then the arithmetical complement of $x = 10 - x$.) It is abbreviated into *ar. co.*

To find the arithmetical complement of the logarithm of a number.*

RULE XIV.

Begin from the left; subtract every figure from 9 *up to the lowest significant figure, which subtract from* 10. *Repeat the cyphers at the end, if any.*

(*a*) When the characteristic is negative it must be added to 9.

Examples.

Ex. 1. Find the ar. co. of 1·79043

(*a*) Ar. co. log. required 8·20957

(*a*) Thus we say, beginning at the left hand, 1 from 9, 9 from 9, 7 from 9, 0 from 9, 4 from 9, and 3 from 10.

The ar. co. of 3·607218 is 6·392782
. . 0·714000 „ 9·286000

Ex. 2. Find the ar. co. of 9·085640

(*b*) Ar. co. log. required 0·914360

(*b*) 9 from 9, 0 from 9, 8 from 9, 6 from 9, 5 from 0, and as the next figure, 4, is the *lowest significant* figure (see Rule), we take it from 10, which leaves 6; lastly, the cypher at the end is repeated.

The ar. co. of $\bar{1}$·217034 is 10·782966
. . $\bar{3}$·178680 „ 12·821320

28. A subtractive quantity is, by this means, made additive. The process is equivalent to subtracting the number from 10, and the reason of it is evident on considering that to add 3 and subtract 10 is the same as to subtract 7. In like manner instead of subtracting $42^m\ 10^s$ for example, we may add $17^m\ 50^s$ (the complement of 60^m), provided we subtract 1^h (or 60^m); and thus any number of quantities, of which some are additive and some subtractive, may be rendered all additive, provided that the larger numbers which are employed in taking the complements be themselves subtractive.

MISCELLANEOUS.

29. We here insert a collection of numbers, the logarithms of which are to be taken out of the Tables.

1.	8	8.	24·6	15.	844·4	22.	4480000	29.	·000000062
2.	0·1	9.	6390	16.	·92096	23.	93·7654	30.	30000·9
3.	4·9	10.	·1463	17.	10000	24.	50000	31.	88590000
4.	38	11.	3·874	18.	9080·8	25.	700090	32.	287·642
5.	380	12.	·0876	19.	·00058	26.	264000	33.	0·003564
6.	100	13.	0·125	20.	·035872	27.	500909	34.	·000856736
7.	·0001	14.	0·0009	21.	·000448	28.	10000000	35.	65480009

30. Required the natural number of the following logarithms:—

1.	2·309630	8.	3·563362	15.	$\bar{3}$·959041	22.	$\underline{5}$·000000	29.	$\bar{1}$·883030
2.	3·676968	9.	0·565021	16.	$\underline{0}$·415974	23.	$\bar{2}$·881955	30.	3·625343
3.	0·954243	10.	5·774152	17.	$\bar{1}$·000000	24.	$\bar{1}$·167317	31.	1·725364
4.	1·698970	11.	3·000000	18.	$\bar{3}$·954243	25.	$\bar{7}$·875061	32.	$\bar{2}$·627407
5.	0·000000	12.	6·394452	19.	$\bar{2}$·716003	26.	0·000186	33.	$\bar{3}$·686216
6.	2·000000	13.	1·415674	20.	0·434294	27.	6·947385	34.	$\bar{4}$·321547
7.	2·564494	14.	$\bar{2}$·954243	21.	5·606389	28.	$\bar{2}$·963081	35.	0·875061

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* A very curious and valuable artifice, discovered by Gunter about 1614.

31. Finally, we recommend the student to commit to memory the following table of logarithms to two places:—

No.	Log.	No.	Log.	No.	Log.
1.	00	4.	60	7.	85
2.	30	5.	70	8.	90
3.	48	6.	78	9.	95

MULTIPLICATION BY LOGARITHMS.

32. In multiplication we proceed by

RULE XV.

1°. *Find the logarithms of the numbers, the product of which is required.* (For the method of taking out the log. of a number see pages 23 to 26).

NOTE.—If any of the quantities is a decimal, either the negative characteristic of that quantity or its arithmetical complement is to be used (see Rules II and III, page 21).

2°. *Add these together, the sum will be the logarithm of the product.*

3°. *Find from the Tables the corresponding number.* (For the method of finding the corresponding number to a log., see pages 27 to 28.)

This will be required product.

NOTE 1.—When both the multiplicand and multiplier are *whole or mixed numbers* the characteristics of the logarithms to be added are all positive, and it is evident that their sum will be positive, and, consequently, the product is a whole or mixed number.

NOTE 2.—Both multiplicand and multiplier being decimals *the characteristics will be negative*, and their sum diminished by the figure—if any—carried from the sum of the mantissæ or positive decimal parts will be negative, and the *product* will also be *a decimal.*

NOTE 3.—When the *arithmetical complement of the indices are used* instead of the negative indices (see Rule III, page 21), if the sum of such characteristics exceeds the sum of tens borrowed, the product will be a whole number; otherwise it will be a decimal (see Exs. 6 and 7, pages 32 and 33).

NOTE 4.—*If some characteristics are positive and the others negative,* find the sum of the positive characteristics, together with any figure that may be carried from the decimal part of the logarithm (bear in mind that the carrying figure is always positive); also add the negative characteristics together; subtract the less of these quantities from the greater and prefix to the difference the sign belonging to the greater. But if a positive and a negative characteristic are exactly equal to each cancel both; this is done in practice by simply drawing the pen through them.

EXAMPLES.*

1. Multiply 77 by 100. The log. of 77 and 100 being taken from the table, we have

77 log. 1·886491
100 log. 2·000000

7700 log. 3·886491

We have here added the logs. of the given factors, and having sought in the Table for the mantissa ·885491, we have found the figures of the nat. no. corresponding to be 7700; the index 3 determines *four* of these to be integral; hence the product is 7700 (Rule IX, page 27).

2. Multiply 3456 by 500.

3456 log. 3·538574
500 log. 2·698970

1728000 log. 6·237544

The mantissa of log., viz, ·237544, is found *exactly* in the Table in a line with 172 and under 8; but as the characteristic 6 requires 7 digits in the integer part, we therefore annex 3 cyphers, which gives 1728000 as the nat. no. corresponding to the proposed log. This is according to Rule XII (*a*), page 28.

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* In these examples, and for several of the subjoined Exercises, the logarithmic is more tedious than the ordinary method of calculation; the purpose here intended being simply to make the student familiar with the process of finding products logarithmically. It must be remembered too, that by the logarithmic process, we generally obtain only an approximate value of the required result.

3. Multiply 963 by 48·9 by common logarithms. The log. of 963 and 48·9 being taken from the Table, we have

963 log. 2·983626
48·9 log. 1·689309

log. 4·672935
(next lower in Table) ·672929 gives 4709

Product 4709·07 92)600(06
552

48

We have here added the logs. of the given factors together, and having sought for the given mantissa ·672935, which is not to be exactly found in the Tables, we obtain the next less mantissa ·672929, the figures of the natural number corresponding to which are 4709; then we subtract the tabular mantissa (·672929) from the given mantissa; the difference is 6, to which two cyphers are annexed, and then we divide by the tabular difference 92, whence we obtain 07 nearly; the remainder, 48, being more than half the divisor, 1 is added to the last figure in the quotient (6); attaching these to the four figures obtained previously, we have 470907; the characteristic 4 determines *five* of these to be integral; hence the product is 4709·7 (Rule IX, page 27). The multiplier containing *one* decimal place, the product is worked out to one place of decimals.

4. Multiply 29·42 by 8·6 by common logarithms.

29·42 log. 1·468643
8·6 log. 0·934498

2·403141
(next lower in Table) 403120* gives 2530

Product 253·012 171)2100(12 +

In this instance the characteristic of the log. of the product is 2, hence the integral part of the natural number must contain 3 figures (Rule IX, p. 27); but since there are decimals in both factors, there must be decimals in the product—as many decimal places as there are in both the multiplier and multiplicand together. In 29·42 are two decimal places and in 8·6 one; hence in the product three decimal places are required, making with the three integral figures, in all six places. Now the next lower mantissa found in the table gives the four corresponding figures 2530, leaving *two* figures to be found. Subtract the mantissa found in the table from the given one, the remainder is 21, to which annex two cyphers (two figures being to be found), dividing by tab. diff. 171 gives 12. (See Rule XIII, page 29.)

5. Multiply ·0567 by ·00339.

Both multiplier and multiplicand being decimals, the characteristics of these factors will be negative, but instead we use their arithmetical complements, thus:—

·0567 log. 8·753583
·00339 log. 7·530200

·0001922 log. 6·283783

Here 10 is borrowed to find the characteristic both of the multiplicand ·0567 and the multiplier ·00339 (see Rule III, page 21). The sum of the characteristics, including the 1 carried from the decimal part of the log., amounts to 16; reject 10 and write down 6 for the index of the log. of product. Then, seeking in the Table for the decimal part, viz., ·283783, the natural number corresponding to it is found to be 1922; and since the sum of the indices 16 is 4 *less* than the 20 borrowed (see Rule XV, Note 3, page 31), the product is a decimal fraction, and the *first significant digit* must stand in the fourth decimal place; hence the product is ·0001922.

Or thus—using negative indices:—

·0567 log. $\bar{2}$·753583
·00339 log. $\bar{3}$·530200

·0001922 log. $\bar{4}$·283783

In adding, when we come to the place of tenths, the process is 5 and 7 are 12, 2 to put down and 1 to carry, and since the characteristics are both negative ($\bar{2}$) and ($\bar{3}$), we diminish their sum ($\bar{5}$) by the number carried (1), which leaves $\bar{4}$ for the index (see Rule XV, Note 2, page 31). We prefix 3 cyphers because the index being $\bar{4}$ the first significant figure of product must stand in the fourth place from the decimal point (Rule X, page 27).

6. Multiply 24000 by ·000783.

24000 log. 4·380211
·000783 log. 6·893762

18·7919 + log. 1·273973

Here 10 was borrowed in determining the index of the log of ·000783, and since the sum of the indices (including 1 carried from the decimal part of log.) is eleven, we reject or pay back the 10 borrowed, which leaves 1 for the index, and the nat. number corresponding is found to be 187919, and we mark off to the right two figures (1 more than the characteristic) whence the answer is 18·7919 +.

Or thus—using negative indices: Ex. 6.

24000 log. 4·380211
·000783 log. $\bar{4}$·893762

18·7919 + log. 1·273973

Here the 1 which is carried after adding 8 and 3 (in the place of tenths), instead of increasing the $\bar{4}$ leaves $\bar{3}$. This is according to Rule XV, Note 4, page 31.

---

* This log. is taken from Hutton, and is incorrect in the last decimal figure, which ought to be 1, as given in Babbage's table; the true log. being ·40312052.

7. **Find the product of ·073 by ·00028 by logarithms.**

$$\begin{array}{rl} \cdot073 & \log.\ 8\cdot863323 \\ \cdot00028 & \log.\ \underline{6\cdot447158} \\ \cdot00002044 & \log.\ 5\cdot310481 \end{array}$$

Here 10 is borrowed in finding the characteristics of both factors (Rule III, page 21). The sum of both characteristics, including the 1 carried from the decimal part of the log., amounts to 15, reject 10 and write down 5 for the index of the log. of the product; and since the sum of the characteristics is *less* than the sum of tens borrowed the product is a decimal (see Rule XV, Note 3, page 31).

Or, using the negative characteristic, thus:

$$\begin{array}{rl} \cdot073 & \log.\ \bar{2}\cdot863323 \\ \cdot00028 & \log.\ \underline{\bar{4}\cdot447158} \\ \cdot00002044 & \log.\ \bar{5}\cdot310481 \end{array}$$

In adding, when we come to the place of tenths, the process is 5 and 8 are 13, 3 to put down and 1 to carry; and this 1 is a positive quantity. Hence in the above, + 1, — 2, and — 4 are to be algebraically added together to form the new characteristic. The sum of the two characteristics (both negative), viz., — 2 and —4 is —6, which diminished by + 1 leaves —5 for the new characteristic. We prefix *four* cyphers, because the characteristic being 5 shows that the first significant figure must stand in the fifth decimal place. (Rule X, page 27.)

8. **Required the product of 17·25, 0·82, and 0·065.**

$$\begin{array}{rl} 17\cdot25 & \log.\ 1\cdot236789 \\ \cdot82 & \log.\ 9\cdot913814 \\ \cdot065 & \log.\ \underline{8\cdot812913} \\ 0\cdot919425 & \log.\ 9\cdot963516 \end{array}$$

Here 10 is borrowed to find the characteristics of log. of both of the second and third factors, and subtracting the sum of the indices, 19 from 20 leaves 1; the sum being *less* than the number borrowed, the product is a decimal, and hence the first significant figure must occupy the first place to the right of the decimal point. (See Rule XV, Note 3, page 31.)

Or thus:—

$$\begin{array}{rl} 17\cdot25 & \log.\ 1\cdot236789 \\ \cdot82 & \log.\ \bar{1}\cdot913814 \\ \cdot065 & \log.\ \underline{\bar{2}\cdot812913} \\ 0\cdot919425 & \log.\ \bar{1}\cdot963516 \end{array}$$

Here we have 1 to carry from the mantissa, which added to the positive characteristic 1 (characteristic of log. 17·25, see above) makes positive 2. Now the sum of the negative indices is $\bar{3}$ (negative 3), and, therefore, since where one is positive and the other is negative, the difference is the characteristic; we have + 2 from $\bar{3}$ leaves $\bar{1}$ for the characteristic (see Rule XV, Note 4, page 31), and the first significant figure of the quotient must occupy the first place to the right of the decimal point. (Rule IX, page 27.)

EXAMPLES FOR PRACTICE.

1. Multiply by logs. 85 by 70; 100 by 10; 369 by 9; and 5671 by 4·7.
2. ,, 538 by 1·74; 601 by 18; 250 by 12·5; and 3964 by 7.
3. ,, 20·42 by 0·5; 3·646 by 0·75; 2·745 by 0·24; and 5·792 by 6·5.
4. ,, 517 by 659; 60·609 by 72; 1·955 by 10·04; and 758875 by 8.
5. ,, 280054 by 50; 30967 by 90; 23716 by 350; and 45670 by 690.
6. ,, 78960 by 400; 756·875 by 8; 94·055 by 74; and 1975 by 10·76.
7. ,, 732 by 543; 58·7 by 66·4; 3000 by 100·14; and 60060 by 700.
8. ,, 543·29 by 3800·62; 87·305 by 4·09; and 209·36 by 46.
9. ,, 348·25 by 7·125; 498·256 by 41·2467; 56·3426 by ·023579; ·123456 by 26813·9.
10. ,, ·0001468 by ·000395; 0·0006 by 10·0004; ·605 by ·0000091.
11. ,, 527·45 by 1·6938; ·007461 by ·3351767; and ·0700397 by ·0086752.
12. ,, ·1 by ·1; ·0001 by ·00001; ·011 by 1·01 and ·00101; and 1000 by 100.

DIVISION BY LOGARITHMS.

33. In division we proceed by

RULE XVI.

1°. ***Find the logarithms of the numbers the quotient of which is required.***

Note.—If the dividend, or divisor, or both, are decimals, the negative characteristic of that quantity, or its arithmetical complement, is to be used.

2°. ***Subtract the logarithm of the divisor from that of the dividend (adding*** 10 ***to the characteristic of this last, if required); the difference will be the logarithm of the quotient.***

3°. ***Find from the Tables the corresponding number.***

This will be the required quotient.

NOTE 1.—It may be necessary to remind the learner that a decimal number is *greater* or *less* than another decimal according to the position of the first figure of each with respect to the decimal point, and, also, the relative values of these figures, and not according to the *number* of decimal figures. For instance ·82 is greater than ·49; because, although the first figure of each is in the same place with respect to the decimal point, yet the first figure (·8) in the first case is greater than the first figure (·4) in the second case. Again, take ·00742 and ·34; the decimal ·34 is the greater, because its first figure (·3) is nearer the decimal point than the first significant figure (·7) in the decimal ·00742.

NOTE 2.—When the divisor is *less* than the dividend the characteristic of the log. of the quotient will come out positive, and the quotient is a whole number; but when the divisor is *greater* than the dividend the characteristic of the log. of quotient will come out negative—the quotient itself being, evidently, a decimal; but if we wish to avoid the use of negative characteristics it will be necessary to add 10 to the characteristic of the dividend when subtracting the logarithm of the divisor, and the characteristic of the remainder is the arithmetical complement of the negative characteristic of quotient.

NOTE 3.—When the characteristic of the divisor is the larger, or when the negative indices are used, the indices are subtracted as follows:—Add the carrying figure (if any) to the index of the divisor, if the latter is positive, but subtract the carrying figure if the index is negative, naming the difference positive or negative the same as the larger; *now change the sign*, and add it algebraically to the other characteristic, as shown in the rule for multiplication. If, for the sake of convenience, the line containing the quantity to be subtracted, when the quantities have been written down one under the other, is called the *take* line, and the quantity from which it is to be subtracted the *from* line, then subtracting in the usual way until we come to the characteristics; if their signs are *alike* take the difference of them, and if the *from* line is the *greater* prefix to the remainder the *given sign;* but if the *take* line is the *greater* prefix the *contrary* of the given sign. If the signs are different, take the *sum* of the characteristics and prefix the sign of the *from* line. The figure borrowed when subtracting the decimal part of the logarithm, when carried to the characteristic, is always to be added, and therefore makes a negative characteristic less, thus 2 carried to $\bar{5}$ makes it $\bar{3}$.

EXAMPLES.

1. Divide 3192 by 76.

The log. of 3192 is taken out according to Rule VII, page 24, and the log. of 76 by Rule V, page 23.

3192 log.	3·504063
76 log.	1·880814
Quotient 42·0 log.	1·623249

2. Divide 944·7 by 2·01.

944·7 log.	2·975294
2·01 log.	0·303196
Quotient 470 log.	2·672098

2. Divide 830772 by 982.

The log. of 830772 is taken out by Rule VIII, page 25. Seek in the left-hand column of the Table, marked No. at the top, for 830 (the first three digits), and also at the top of the page in one of the horizontal columns for the fourth figure 7, then in a line with the first and under the latter we have 919444. In a line with this quantity and in the right-hand column marked *Diff.* stands 52, which multiplied by the remaining figures of the nat. number, viz 72, produces 3744; then cutting off two digits from these (since we multiplied by *two* digits) it becomes 37, which being added to 919444, the mantissa of 8307, makes 919481, and with the characteristic 5, is 5·919481. The work will stand thus:—

Log. 8307 =	919444	Tab. diff.	52
Diff. for 72 +	37	×	72
	919481		104
			364
			37,44

830772 log.	5·919481
982 log.	2·992111
Quotient 846·0 log.	2·927370

4. **Divide 3672 by 51000.**

3672 log. 3·564903
51000 log. 4·707570

Quotient ·072 log. 8·857333

Here 10 is added to the characteristic of the dividend before subtracting log. of divisor, and to avoid negative characteristics. The divisor being greater than the dividend the quotient is evidently a decimal. (See Note 1, page 34).

Or thus, using negative characteristics:—

3672 log. 3·564903
51000 log. 4·707570

·072 log. $\bar{2}$·857333

In this instance, when carrying 1 to the characteristic 4, we have to subtract 5 from 3, which gives —2 (negative 2); or by Note 2.—Take the difference of characteristics, as they are of the same sign (+), and prefix a contrary sign (—) to the remainder, the *take* line being the greater.

5. **Divide ·01958 by ·4828.**

·01958 log. 8·291813
·4828 log. 9·683767

·04056 log. 8·608046

Before subtracting the log. of divisor from that of the dividend 10 must be added to the characteristic of the dividend; the quotient is therefore a decimal. Or using negative characteristics the work will stand thus:—

·01958 log. $\bar{2}$·291813
·4828 log. $\bar{1}$·683767

·04056 log. $\bar{2}$·608046

To obtain the characteristic of the quotient ($\bar{2}$) the 1 that is carried, and which is positive, is added to the $\bar{1}$ producing 0, which has then to be subtracted from $\bar{2}$, leaving $\bar{2}$.

6. **Divide 26843 by ·03010.**

Log. 2684 = 428782* Tab. diff. 162
Diff. for 3 = + 49 × 3

Log. 26843 = 428831 48,6
or 49

26843 log. 4·428831
·03010 log. 8·478566

891794 log. 5·950265
219

* Raper 3.

49)4600(94 nearly.

Or thus:—

26843 log. 4·428831
·03010 log. $\bar{2}$·478566

891794 log. 5·950265

Here the characteristic of the second log. is $\bar{2}$, but following the rule, we have changed it to positive 2. The characteristic of first log. being positive 4, the two are added, the sum being positive 6, but having borrowed 1, the correct characteristic is 5, and being positive, the quotient will contain 6 integral figures.

7. **Divide ·8 by ·0000002.**

·8 log. 9·903090
·0000002 log. 3·301030

4000000 log. 6·602060

The divisor being *less* than the dividend, the quotient is evidently an integer, and the characteristic denotes that it is a whole number consisting of seven places of figures; cyphers are therefore annexed to make up the required number

Or, Log. ·8 = $\bar{1}$·903090
Log. ·0000002 = $\bar{7}$·301030

Log. 4000000 = 6·602060

The characteristics are both negative, take their difference, and prefix to the remainder the contrary sign to the given one, as the take one is the greater.

8. **Divide ·00815 by ·000275.**

0·00815 log. 7·911158
0·000275 log. 6·439333

Quotient 29·6364 log. 1·471825

Or, ·00815 log. $\bar{3}$·911158
·000725 log. $\bar{4}$·439333

29·6364 log. 1·471825

The index of the divisor $\bar{4}$ being supposed changed to positive 4, the difference between which and $\bar{3}$ leaves positive 1 for index of quotient. Or, proceeding according to Note 3—Since the characteristics have *like* signs, take their difference; the remainder takes a positive sign, or a contrary sign to the *take* line, which is the greater.

9. **Divide ·012550 by 1004000.**

·012550 log. 8·098644
1004000 log. 6·001734

·0000000125 log. 2·096910

The divisor being greater than the dividend, the quotient is a decimal.

Or, ·012550 log. $\bar{2}$·098644
1004000 log. 6·001734

·0000000125 log. $\bar{8}$·096910

The characteristic of the dividend is $\bar{2}$, that of the divisor positive ; then according to Note 2, the signs being *unlike*, take the *sum* of the characteristics, prefixing the sign of the *from* line (—).

EXAMPLES FOR PRACTICE.

1. Divide 6391 by 77; 21636 by 36; 93750 by 750; and 218432 by 495.
2. „ 9504000 by 98; 45000 by 9; 6071000 by 8; and 58469 by 981.
3. „ 783254 by 250689; ·79632 by ·019354; ·0092852 by ·0003461.
4. „ ·0008464 by ·0002852; ·05826 by ·95381; ·019354 by ·79632; ·00005 by 2·5, by 25, and by ·0000025.
5. „ 77000000 by 9999; 680300 by 681500; 100·002 by 1·0012.
6. „ 999999 by 10101; 57634·1 by 276·4; 69·7565 by ·97564; and 352740 by 56780.
7. „ 40048000 by 800; 11123100 by 340; 1869210 by 90; and 1875000 by 15000.
8. „ 248·25 by 364·87; ·235316 by 293·864; 5·6949 by 53·058; 3876000 by 1200.
9. 19 ÷ 72; 19 ÷ ·72; ·19 ÷ ·72; 19 ÷ ·0072; 6 ÷ ·0000003; and 9 ÷ ·0000003.
10. ·1 ÷ ·0004572; 1 ÷ ·0011636; 11·2221 ÷ 111; 4000 ÷ ·000125; and ·562625 ÷ 52643.
11. ·0001 ÷ ·0001; 1000000 ÷ ·0000001; 10 ÷ 100; ·00000001 ÷ ·000001; 1000 ÷ $\frac{1}{10}$.

34. When it is proposed to find the value of an expression in which both multiplication and division are signified, the sum of the logarithms of the factors of the dividend, diminished by the sum of the logarithms of the factors of the divisor, will be the logarithm of the value required.

EXAMPLE.

Thus: to find the value of $\frac{209 \times 573 \times 63}{287 \times 2101}$

209 log. 2·320146
573 log. 2·758155
63 log. 1·799341

6·877642
5·780308

Ans.: 12·5122 log. 1·097334

287 log. 2·457882
2101 log. 3·322426

5·780308

35. It is very often expedient to transform the logarithm of a divisor into that of a multiplier, and it is customary, in such calculations, to avoid not only negative logarithms, but negative indices also, by substituting for a subtraction logarithm its arithmetical complement *(See No. 27, page 30)*. This makes the operation consist of a single addition, only we must diminish the result by subtracting 10 for every arithmetical complement that has been used. By this means the process of division is less open to error from mistakes when logarithms with negative characteristics would be subtracted.*

To apply this method to the example above:—Having found in the Table the log. of the divisor 287, we may at once transform it into the addition logarithm 7·542118, and similarly, for the log. of 2101 we may write 6·677574, and then the calculation will proceed continuously as follows:—

209 log. 2·320146
573 log. 2·758155
63 log. 1·799341
287 ar. co. 7·542118 — 10
2101 ar. co. 6·677574 — 10

1·097334 *Ans.*: 12·5122

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* To divide by any number n is the same in effect as to multiply by its reciprocal $\frac{1}{n}$ (that is, the quotient of unity divided by that number, and is so called from an exchange of places between a numerator and denominator: thus, the reciprocal of $\frac{3}{4}$ is $\frac{4}{3}$, that of 6, or $\frac{6}{1}$, is $\frac{1}{6}$). Therefore to subtract log. n is the same in effect as to add log. $\frac{1}{n} = 0 - \log. n$.

EXAMPLES FOR PRACTICE.

1. $\dfrac{7 \times 8{\cdot}73}{{\cdot}54963}$ $\dfrac{84 \times {\cdot}00769 \times 683}{598 \times {\cdot}0000146 \times {\cdot}039}$ $\dfrac{8{\cdot}4 \times {\cdot}0769 \times {\cdot}00683}{59{\cdot}8 \times {\cdot}0000146 \times {\cdot}0039}$

2. $\dfrac{67{\cdot}038 \times {\cdot}010705 \times 4{\cdot}1525}{{\cdot}7854 \times 3{\cdot}1416 \times {\cdot}086725}$ $\dfrac{28{\cdot}045 \times 1{\cdot}3564 \times {\cdot}0942537}{48{\cdot}375 \times 2{\cdot}71828 \times 52357}$

3. Divide $\cdot063\mathrm{14} \times {\cdot}7438 \times {\cdot}102367$ by $\cdot007241 \times 12{\cdot}9476 \times {\cdot}496523$. and compare the result with the product of $8{\cdot}71979 \times {\cdot}057447 \times {\cdot}0206168$.

36. Degree of Dependence.—The number of places of figures which may be obtained in a result derived from any table of logarithms is the same, usually rejecting prefixed cyphers, as the number of decimals to which the logarithms are carried. But towards the end of the Table the last place thus obtained cannot always be depended upon within a unit, that is, provided the mantissa of log. is greater than ·9388. Thus, for instance, the log. 3·7575 corresponds to the no. 5721 and the log. 3·7576 to 5722, nearly. It will moreover be noticed that the log. tables are, in fact, useless for dealing with numbers consisting of more than eight places of figures. Thus, for instance, we should not find any difference between the log. of 23·47832 and the log. of 23·4783297.

This remark should be kept in mind, because it is mere waste of time to employ more figures than are required to insure a certain degree of precision in the result

TRIGONOMETRY.

MEASURES OF ANGLES AND ARCS.

37. **Trigonometry** is that branch of Mathematics which treats of methods of subjecting angles and triangles to numerical computation.

In the present state of science it has a more extended signification, and is understood to embrace all theorems and formulæ which express the relations which exist between angles and certain quantities dependent on them, called Trigonometrical Functions.

38. **Plane Trigonometry** treats of methods of computing plane angles and triangles.

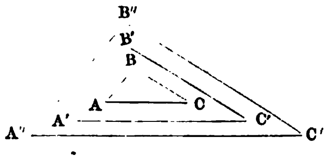
39. By the solution of a triangle in trigonometry is meant the *computation* of unknown parts of the triangle from given ones.

The triangle has six parts; three angles and three sides. It is shown in geometry, that when any three of these parts are given, provided one of them is a side, the triangle may be constructed, and the unknown parts found by mechanical measurement.

In the same cases, by trigonometry, we compute the unknown parts from the three given ones, without resorting to construction and measurement: a method of inferior accuracy, on account of the unavoidable imperfections of the instruments employed, and the difficulty of distinguishing with the eye the smallest sub-divisions of lines and angles.

But here also the case is excluded in which the three angles are given without a side, because there may be an indefinite number of plane triangles, whose angles are equal to the same three given ones, as in Fig. 1, the triangles A B C, A′ B′ C′, &c., are similar, and their sides are proportional, or the ratio of A B to A C is equal to the ratio of A′ B′ to A′ C′, &c., so that the ratios of the sides to each other are fixed, or determinate, although the absolute lengths of these sides are indefinite.

Fig. 1.

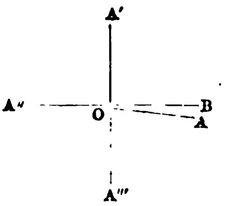


40. Now, in order to subject a triangle to computation we must first express the sides and angles by numbers. For this purpose proper units of measure must be adopted.

The units of measure for the sides of plane triangles is a straight line, as an inch, a foot, a mile, &c., and the number expressing a side is the number of units of the adopted kind that the side contains.

41. The units by which angles are expressed are, the degree, minute, and second, distinguished by the characters ° ′ ″.

Fig. 2.



A *degree* is an angle equal to 1-90th of a right-angle; or a degree is 1-360th of the whole angular space about a point, or 1-360th of four right-angles. Thus, Fig. 2, if the angular space about O is divided into 360 equal parts, of which A O B is one, then A O B is one degree. The right-angle will be expressed by 90°, two right-angles by 180°, and the whole angular space about a point by 360°

A *minute* is an angle equal to 1-60th of a degree.

Therefore $1^\circ = 60'$; and the right-angle $= 90 \times 60 = 5400'$

A *second* is an angle equal to 1-60th of a minute.

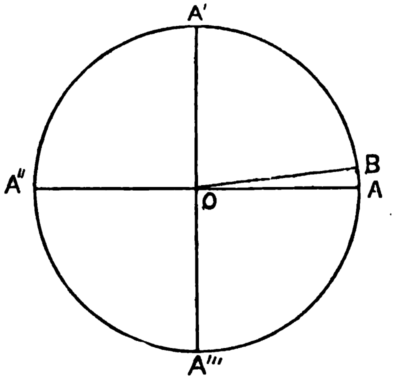
Therefore $1' = 60''$; $1^\circ = 60 \times 60'' = 3600''$; and a right-angle $= 90 \times 60 \times 60 = 324000''$.

Angles less than seconds are sometimes expressed by *thirds*. But the more convenient method is to express them as decimal parts of a second.

MEASURES OF ARCS.

42. Since the angles at the centre of a circle are proportional to the arcs of the circumference intercepted between their sides, these arcs may be taken as the measures of the angles, and we may express both the arc and the angles by the number of *units of arc* intercepted on the circumference.

Fig. 3.



The units of arc are also the degree, minute, and second. They are the arcs which subtend angles of a degree, a minute, and a second respectively, at the centre. A degree of an arc is thus always 1-360th part of the circumference, whatever the radius of the circle may be, and we obtain the same numerical expression of an angle, whether we refer it directly to the angular unit, or to the corresponding unit of arc. The right angle A O A″, Fig. 3, and its measure, the quadrant A A′, are therefore both expressed by 90°; the semicircumference by 180°; and the whole circumference by 360°.

43. The radius of the circle employed in measuring angles is thus arbitrary, and we may assume for it such a value as will most simplify our calculations.

44. The *Complement* of an angle or arc is the remainder obtained by subtracting the angle or arc from 90°.

Thus the complement of 60° is 30°; of $49^\circ\ 32'$ is $40^\circ\ 28'$; of $56^\circ\ 3'\ 48''$ is $33^\circ\ 56'\ 12''$.

45. The *Supplement* of an angle or arc is the remainder obtained by subtracting the angle or arc from 180°.

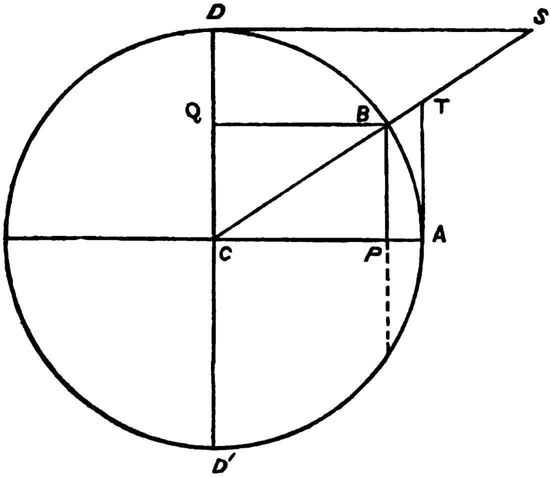
Thus the supplement of 60° is 120°; of 29° 37′ is 150° 23′; of 48° 26′ 42″ is 131° 33′ 18″.

46. Having expressed the sides and angles of triangles by numbers, we have next to find such relations between them as shall enable us to combine these two different species of quantities in computation.

47. Trigonometrical Functions of an Arc.—There are certain *lines* called trigonometrical functions of the *arcs* on which they depend, and which are defined as follows:—

With C as centre and any line, C A, as radius, describe a circle. Through C draw two diameters, AA′ and DD′, at right-angles. Let AB be any arc measured *upwards* from the radius C A. From B the end of the arc let fall B P perpendicular on C A, and B Q perpendicular on C D, and at the points A and D draw the lines A T and D S touching the circle, and meeting the radius C B produced in the points T and S.

Fig. 4.



DEFINITIONS.

The **Sine** of an arc, or of the angle at the centre measured by that arc, is the straight line drawn from one extremity of the arc perpendicular to the diameter, passing through the other extremity.

The *Sine* of the arc A B is the line B P.

The **Cosine** of an arc is the perpendicular let fall from the end of the arc on the diameter passing through the end of the first quadrant.

The *Cosine* of the arc A B is the line B Q = C P.

The **Tangent** of an arc, or the angle which it measures, is a straight line touching the circle at the beginning of the arc, and terminated by the radius produced.

The *Tangent* of an arc A B is the line A T.

The **Cotangent** of an arc is the right line touching the circle at the end of the first quadrant, and terminated by the radius produced drawn through the end of the arc.

The *Cotangent* of the arc A B is the line D S.

The **Secant** of an arc is the straight line drawn from the centre of the circle to the remote extremity of the tangent.

The *Secant* of the arc A B is the line C S.

The **Cosecant** of an arc is the right line drawn from the centre of the circle through the end of the arc, and terminated by the cotangent.

The *Cosecant* of the arc A B is the line C S.

The **Versed Sine** of an arc is the right line which is intercepted between the beginning of the arc and the foot of the sine.

The *Versed Sine* of the arc A B is the line A P.

The **Coversed Sine** of an arc is the right line which is intersected between the end of the quadrant and the foot of the cosine.

The *Coversed Sine* of the arc A B is the line D Q.

It is evident from the figure that B Q will be the sine of the arc B D; C Q its cosine; B S its tangent; A T its cotangent.

Since D B and B A are complements of each other, and since B A is equal to Q C and B Q to P C, we have,

B P which is the sine B A = Q C which is the cosine of B D.

C P which is the cosine of B A = Q B which is the sine of B D.

T A which is the tangent of B A is the cotangent of B D.

D S which is the cotangent of B A is the tangent of B D.

Hence the following—

The sine of an angle is equal to the cosine of its complement; the cosine to the sine of its complement; the tangent to the cotangent of its complement.

It is manifest from the figure, that if the point B descends to A, the arc B A is 0, and then,

The sine	B P = 0
,, cosine	C P = radius.
,, tangent	T A = 0
,, cotangent	D S is infinite.
,, secant	C B = radius.
,, cosecant	C S is infinite.
,, versed sine	P A = 0
,, surversed sine	A′ P = twice the radius.

48. Also, if the point B be in the centre of D A, then B A = 45°, and it is easily seen that

The sine = the cosine.
,, tangent = ,, cotangent.
,, secant = ,, cosecant.

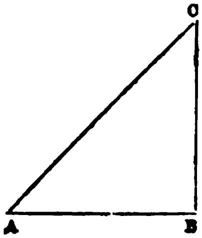
49. Again, if the point B travel to F, then the arc B A becomes 90°, and its

Sine = radius.
Cosine = 0
Tangent is infinite.
Cotangent = 0
Secant is infinite.
Cosecant = radius.

DEFINITIONS OF THE TRIGONOMETRICAL RATIOS.

50. We have hitherto spoken of the sine, cosine, &c., of an angle as *lines*; but such is only correct when the length of a radius of a circle is known or understood. In practice they are regarded not as lines, but as quantities; they are, in fact, fractions.

Fig. 5.



In a triangle, A B C, let the angle C A B be denoted by A, then the *trigonometrical ratios* are the fractions that can be formed by computation of the measures of the three sides of the right-angled triangle C A B, taking them two and two together. It is evident that only six such fractions can be found in this manner, namely:—

$\frac{BC}{AC}$ and its reciprocal expression $\frac{AC}{BC}$

$\frac{BC}{AB}$ and its reciprocal expression $\frac{AB}{BC}$

$\frac{AC}{AB}$ and its reciprocal expression $\frac{AB}{AC}$

To connect these fractions with one of the angles of the triangle, as A, let us call the side A C opposite the right-angle the hypothenuse, the side C B opposite the angle in question the perpendicular, and the remaining side A B adjacent to the angle the base; then the trigonometrical ratios of an angle are named as follows: the perpendicular divided by the hypothenuse is called the *sine* of the angle; the hypothenuse divided by the base is called the *cosecant* of the angle; the perpendicular divided by the base is called the *tangent* of the angle; the base divided by the perpendicular is called the *cotangent* of the angle; the hypothenuse divided by the base is called the *secant* of the angle; and the base divided by the hypothenuse is called the *cosine* of the angle. Another term used in Trigonometry is *versine* of an angle. These definitions will be more readily learned by writing them down in the form of fractions, thus:—

$\frac{BC}{AC}$, that is, $\frac{\textit{perpendicular}}{\textit{hypothenuse}}$ is called the *sine* of the angle A (*a*).

$\frac{AC}{BC}$, that is, $\frac{\textit{hypothenuse}}{\textit{perpendicular}}$ is called the *cosecant* of the angle A (*b*).

$\frac{BC}{AB}$, that is, $\frac{\textit{perpendicular}}{\textit{base}}$ is called the *tangent* of the angle A (*c*).

$\frac{AB}{BC}$, that is, $\frac{\textit{base}}{\textit{perpendicular}}$ is called the *cotangent* of the angle A (*d*).

$\frac{AC}{AB}$, that is, $\frac{\textit{hypothenuse}}{\textit{base}}$ is called the *secant* of the angle A (*e*).

$\frac{AB}{AC}$, that is, $\frac{\textit{base}}{\textit{hypothenuse}}$ is called the *cosine* of the angle A (*f*).

When the cosine of A is subtracted from unity the remainder is called the *versed sine* of A. When the sine of A is subtracted from unity the remainder is called the *coversed sine* of A.

51. For shortness' sake we usually denote an angle by some single letter, as for instance A; and we write the names of the functions above defined, viz., the *sine*, *cosine*, *tangent*, *cotangent*, *secant*, *cosecant*, *versed sine*, and *coversed sine*, thus: sin. A, cos. A, tang. A, cot. A, sec. A, cosec. A, vers. A, covers. A; thus the above definitions may be expressed as follows:—

$$\text{Sin. A} = \frac{BC}{AC} \qquad \text{Cos. A} = \frac{AB}{AC}$$

$$\text{Tang. A} = \frac{BC}{AB} \qquad \text{Cot. A} = \frac{AB}{BC}$$

$$\text{Sec. A} = \frac{AC}{AB} \qquad \text{Cosec. A} = \frac{AC}{BC}$$

$$\text{Vers. A} = 1 - \text{cos. A}. \qquad \text{Covers. A} = 1 - \text{sin. A}.$$

52. The *sine*, *cosine*, *tangent*, *cotangent*, *secant*, *cosecant*, *versed sine*, and *coversed sine* of an angle are called the *Trigonometrical Ratios* of the angle. It will be seen from the definitions that the term *ratio* is appropriate, because each of the quantites defined is the *ratio* of one length to another; that is, each of the quantities is some arithmetical number or fraction. The *Trigonometrical Ratios* have been sometimes called *Trigonometrical Functions*,* and sometimes *Goniometrical Ratios* or *Functions*.

53. Since the sum of the two acute angles of a right triangle is one right-angle, or 90°, they are, by Art. 44, complements of each other. This affords another method of defining some of the Trigonometrical Ratios; after defining, as in Art. 50, the *sine*, *tangent*, and *secant* of an angle, we may say:

The cosine of an angle is the sine of the complement of that angle;

The cotangent of an angle is the tangent of the complement of that angle;

The cosecant of an angle is the secant of the complement of that angle.

For in the triangle CAB, the angle ACB is the complement of the angle A; and

$$\text{Sine of ACB} = \frac{\textit{perpendicular}}{\textit{hypothenuse}} = \frac{AB}{AC} = \text{cos. A.}$$

$$\text{Tang. ACB} = \frac{\textit{perpendicular}}{\textit{base}} = \frac{AB}{BC} = \text{cot. A.}$$

$$\text{Sec. ACB} = \frac{\textit{hypothenuse}}{\textit{base}} = \frac{AC}{BC} = \text{cosec. A.}$$

These results may also be expressed thus:—

The sine of an angle is the cosine of the complement of that angle;

The tangent of an angle is the cotangent of the complement of that angle;

The secant of an angle is the cosecant of the complement of that angle.

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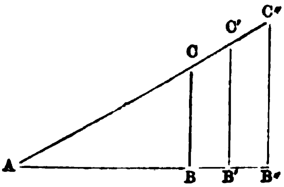
* By the Trigonometrical *functions* of the angle is meant quantities which depend upon that angle for their value, and (conversely) which being given determine the value of the angle.

54. ***The Trigonometrical Ratios remain unchanged so long as the angle remains unchanged.***

As every oblique triangle may be resolved into two right-angles by dropping a perpendicular from one of the angles upon the opposite side, the solution of all triangles is readily made to depend upon that of right-angles. Let us, therefore, consider a series of right triangles, ACB, AC′B′, AC″B″, &c., Fig. 6, which have a common angle A. The angles at C, C′, C″, being also equal, the triangles are similar; and by geometry—

Fig. 6.



$$CB : AC = C'B' : AC' = C''B'' : AC''.$$

Or by the definition of ratios and proportion—

$$\frac{CB}{AB} = \frac{C'B'}{AB'} = \frac{C''B''}{AC''}$$

In like manner it follows that—

$$\frac{CB}{AB} = \frac{C'B'}{AB'} = \frac{C'B'}{AB''}$$

$$\text{and } \frac{AC}{AB} = \frac{AC'}{AB'} = \frac{AC''}{AB''}$$

Hence it appears that the *ratios of the sides to each other are the same in all right triangles having the same acute angle;* and, therefore, if these ratios are known in any one of these triangles, they will be known in all of them.

These ratios, then depending on the value of the angle alone, without regard to the absolute lengths of the sides, may be considered as indices of the angle, and have received special names, as above.

55. With respect to the use and importance of the trigonometrical ratios we may here briefly remark, that since we are not able to compare together the angles and sides of a triangle (for we cannot say that an angle is three or more times greater than a side, since these quantities have different units of measurement) it has been found convenient to take certain lines or fractions such as $\frac{BC}{AC}$, &c., and compute their numerical value for different angles, and record these values in tables. Now these fractions will evidently depend for their value on the magnitude of the angles themselves; and, if we know the fraction, we shall know by means of the tables the angle corresponding to it. Moreover, we can compare the side of a triangle with this fraction, since both quantities are expressed in the same kind of measure, namely, linear measure; and then, by reference to the table, discover the relation of the side to the angle itself.

TRIGONOMETRICAL TABLES.

56. There are two kinds of trigonometrical tables; the first, called the *Table of Natural Sines, Cosines, &c.*, contains the numerical values of the sines, cosines, tangents, &c., that is, of the trigonometrical ratios for each given value of the angle; the second, called the *Table of Logarithmic Sines, &c.*, contains the logarithms of the numbers in the first Table.*

TABLE OF NATURAL SINES, &c.

57. The trigonometrical functions or ratios are numbers which are capable of being calculated from geometrical principles, and accordingly certain series have been investigated, and certain algebraic expedients devised for the general purpose of determining the trigonometrical ratios. With such aid the sines, cosines, &c., of all angles from 0° to 90° (*i.e.*, for all values of A, from $A = 0$ up to $A = 90$) have been computed to several places of decimals and arranged in tables called *Tables of Natural Sines, Cosines, &c.* In some tables the angles succeed each other at intervals of 1″, in others at intervals of 10″; but in ordinary tables (as Table XXVI, Norie) at intervals of 1′, and to the last mentioned we shall refer.

58. The statement of the method by which such tables are constructed is unsuitable to the pages of the present work. The mode of using them in computation we shall now proceed to explain.

59. The arrangement of this table will be understood from a simple inspection. It contains the sines, cosines, &c., of angles between zero and 90°, generally for every minute, and the fluctuations of angles containing a number of degrees, minutes, and seconds, have to be found by interpolation similar in their nature to those that are required to be used in tables of logarithms of numbers. This interpolation is based upon the supposition that the differences of the sines, &c., are proportional to the differences of the angles, and this proportion, though theoretically inexact, gives, in general, a sufficient approximation, provided the difference of the angles of the table are sufficiently small.

60. Referring to the Tables (Table XXVI, Norie) it will be seen that the degrees are given at the *top* of the column, and the minutes down the *left* hand side of the page for the sines.

And, for the cosines, the degrees are given at the *bottom* of the page, and the minutes up the *right* hand side of the page.

The difference of the trigonometrical ratios for 100″ are given at the foot of each column.

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* The usual trigonometrical tables are given in conjunction with tables of logarithms, and they more frequently give logarithms only than sines, cosines, &c., themselves. When logarithms were invented they were called *artificial* numbers, and the originals for which logarithms were computed, were accordingly called *natural* numbers. Thus, in speaking of a table of sines, to express that it is not the logarithms of the sines which are given, but sines themselves, that table would be called a table of *natural* sines, and the logarithms of these would be called not *logarithms of sines* but *logarithmic sines, &c.*

61. In using these Tables, we have either to find the sine, cosine, &c., of an angle whose value is given in degrees (°), minutes (′), and seconds (″); or to find the corresponding angle in degrees, minutes, and seconds.

62. If the value of the angle be given in degrees and minutes only, the sine, cosine, &c., is found directly from the Tables, in which are registered the values of the trigonometrical ratios.

All the numbers contained in such Tables as Norie's Table XXVI must be understood as decimals.

Thus, nat. sine 7° 7′ = ·123890
„ sine 59 40 = ·863102
„ cosine 15 30 = ·963630
„ cosine 71 12 = ·322266

63. As the sines, cosines, &c., pass through all their possible *numerical* values while the angle varies from 0° to 90°, the tables are not extended beyond 90°; such computations would be superfluous, for the sine or cosine of an angle between one and two right angles, viz., of an angle greater than 90° is the same in numerical value as the sine, cosine, &c., of an angle as much below 90°, and is known from the recorded sine or cosine of its supplement. (Art. 45, page 40.)

Whence also

Nat. sine 156°42′ = sine 23°18′ = ·395546
„ cosine 108 48 = cosine 71 12 = ·322266
„ sine 140 16 = sine 39 44 = ·639215
„ cosine 140 16 = cosine 39 44 = ·769028

64. Or, we may (Art. 44, page 39) deduct 90° from the given angle, and take from the table the *complemental* functions of the remainder; thus,

sine 140°16′ = cos. 50°16′ = &c.
cos. 140 16 = sine 50 16 = &c.

which is the better practical method, as the subtraction of 90° may be performed mentally.

65. If the angle contains seconds, we must proceed by the *method of proportional parts*, as in the following examples:—

RULE XVI.

1°. *Find from the Table the nat. sine, cosine, &c., which corresponds to the degrees and minutes.* (Norie, Table XXVI.)

2°. *Multiply the difference by the seconds, and divide by* 100.

Note.—To divide by 100 we have merely to *cut off the two* right-hand figures.

3°. *If the required quantity be a nat. sine, tangent, or secant, add the result to the last figures obtained in* 1°; *if it be a cosine, cotangent, or cosecant, subtract.* The result will be the required sine, cosine, &c.

Note 1.—The reason of this rule is founded on the principle that for a small interval, such as one minute, the increase of the sine is proportional to the increase of the angle.

Note 2.—It is necessary to bear in mind that the sine, tangent, and secant (under 90°) for which the tables are constructed *increase* as the *arc increases*, whilst the cosine, cotangent, and cosecant *decrease* as the *arc increases*. This will require the corrections connected with a sine, a tangent, or a secant to be added, and those connected with a cosine, a cotangent, or a cosecant to be subtracted whether arcs or their functions be sought from the tables.

Examples.

Ex. 1. Find the nat. sine of 12° 44′ 27″.

Nat. sine 12° 44′ = ·220414

Tab. diff. $\frac{473 \times 27}{100} = +\ 128$

·220542

Ans.: Nat. sine 12° 44′ 27″ = ·220542

To obtain the parts for the second we multiply the tabular difference by the number of seconds and divide by 100, thus:—

Tab. diff. 473
No. of seconds × 27
3311
946
127,71
128 nearly.

Ex. 2. Find the nat. cosine of 31° 28′ 42″.

Nat. cosine 31° 28′ = ·852944

Tab. diff. $\frac{253 \times 42}{100} = -\ 106$

·852838

Ans.: Nat. cosine 31° 28′ 42″ = ·852838

Tab. diff. 253
Seconds × 42
506
1012
106,26
106

Examples for Practice.

To find the nat. sine of

1. 34° 48′ 15″ 2. 60° 7′ 18″ 3. 21° 44′ 21″ 4. 86° 3′ 17″

To find the nat. cosine of

1. 80° 22′ 22″ 2. 5° 22′ 10″ 3. 46° 31′ 41″ 4. 8° 19′ 17″

66. If the value of the sine, cosine, &c., be given, and it is required to find the angle, we use the following rule:

RULE XVII.

1°. *Find in the Tables the next lower nat. sine, nat. cosine, &c., and note the corresponding degrees and minutes.*

2°. *Subtract this from the given sine, cosine, &c., multiplying the difference by* 100; *divide by the tabular difference, and consider the result as seconds.*

3°. *If the given value be that of a sine, tangent, or secant, add these seconds to the degrees and minutes foumd in* 1°; *if it be that of a cosine, cotangent, &c., subtract.* The result will be the required angle.

Note.—In taking out the angle for a natural cosine we may take out the *next greater natural cosine*, and subtract the given natural cosine from it; and having found the seconds (″), as above, they are *additive*. The trigonometrical ratio corresponding to the *next less angle* being written down in every case, confusion will be avoided, as the additional seconds will always be *additive*.

Examples.

Ex. 1. Given the natural sine = ·732156: find the angle.

Given nat. sine 732156
Sine 47° 4′ = 732117 next lower in Table XXVI, Norie.

Tab. diff. = 327 327)39,00(3″ nearly (additional seconds for nat. sine.)
981 *Ans.:* 47° 4′ 3″.

The log. 732156 is sought for in Table XXVI, Norie, but as it cannot be found exactly, the next less is taken which corresponds to 47° 4′. The difference of the logs. is then found, two cyphers added (which is equivalent to multiplying by 100), and the product divided by the tabular difference; the quotient is the additional seconds.

Ex. 2. Given the natural cosine 853267: find the angle.

Given nat. cosine 853267
Cosine 31° 26′ = 853248 next lower in Table XXVI, Norie.
Tab. diff. = 253 253)1900(7″ (to be *subtracted*).
1771
129 *Ans.*: 31° 25′ 53″.

31° 26′ 0″
− 7
31 25 53

Ex. 3. Find the angle whose natural cosine is 728713.

Proceeding according to Note, page 47.

Here nat. cosine of required angle = ·728713
Nat. cosine of next less angle, or 43° 13′ = 728769
Tab. diff. = 334 334)5600(17″ nearly, to be *added*.
334
2260
2338

∴ angle required = 43° 13′ 17″.

EXAMPLES FOR PRACTICE.

Given the nat. sines, to find the angle.

1. ·898002 2. ·8 3. ·444 4. ·20389 5. $\frac{163}{308}$ or ·529221 6. ·96

Given the nat. cosine, to find the angle.

1. ·448807 2. ·948397 3. ·514841 4. ·974822 5. 999000 6. ·6

TABLES OF LOGARITHMS OF TRIGONOMETRICAL RATIOS.

67. The Trigonometrical Ratios being numbers, have logarithms that correspond to them. In practice the logarithmic are generally far more useful than the natural sines, &c., though the latter are often necessary, or in some simple kinds of calculation, preferable.

68. As the sines and cosines of all angles, and the tangents of angles less than 45°, are less than radius or unity, being proper fractions, the logarithms of the value of these quantities, properly, have negative characteristics. In order to avoid the inconvenience of printing negative logarithms, and for other reasons, 10 *is added to* the characteristic before it is registered in the table of logarithmic sines, &c., so that we find the characteristic 9 instead of $\bar{1}$, 8 instead of $\bar{2}$, &c.

Thus, on referring to the Table of Natural Sines (Table XXVI, Norie), we find natural sine of 16° = ·275637. If we calculate the logarithm of ·275637, we find its value is $\bar{1}$·440338; if to this 10 is added we find that

Log. sine 16° = 9·440338.

To preserve uniformity, the characteristics of the logarithms of all the other ratios, namely, of the log. tangents, cotangents, secants, and cosecants are increased by 10. In trigonometrical operations this is convenient, but principally because the extraction of roots very seldom occurs.

It may be observed here that the uniform addition of 10 to the characteristic gives the logarithm of 10000 *million* times the natural number.

Thus, 9·599327 is the log. of 3979486000, and this latter number is the natural sine corresponding to a radius of 10000 *millions*, instead of a radius of unity.

69. Usual arrangement of Tables of Logarithmic Sines, Cosines, &c.—The table of logarithmic sines, cosines, tangents, cotangents, secants, and cosecants, contain all arcs from zero (0°) through all magnitudes up to 90°, the log. of radius, as just stated, being 10. At the top of the page is placed the number of degrees, and in the left-hand column each minute of the degree, opposite to which are arranged the numerical values of the log. sine, cosine, &c., of the corresponding angle in these columns, at the *top* of which these terms are placed. The headings of the columns run along the *top*, thus, as far as 44°. The degrees from 45° to 90° are placed at the bottom of the page, and the minutes of the degree arranged in a right-hand column, so that the angles read off on the right-hand side are complemental to those read off at the points exactly opposite on the left-hand side, the values of the sines, cosines, tangents, &c., being found in the columns at the *bottom* of which those terms are found. This arrangement is rendered practicable by the circumstance of every angle between 45° and 90° being the complement of another between 45° and 0°, every sine of an angle less than 45° is the cosine of another greater than 45°, every tangent is a cotangent, &c.; the sines, tangents, &c., of angles being respectively equal to the cosines, cotangents, &c., of the complements of the same angle. (Art. 44.)

The following shows the usual arrangement of such tables:—

M	Sin.	D.	Cosec.	Tan.	D.	Cot.	Sec.	D.	Cos.	M
M	Cos.	D.	Sec.	Cot.	D.	Tan.	Cosec.	D.	Sin.	M

Besides the columns headed "sine, tangent," &c., are three smaller columns headed "D." or "Diff." They contain, in most tables, the differences between the values of the consecutive logarithms in the contiguous columns on either side, but corresponding to a change of 100″ in the arc (not the difference corresponding to 60″ of arc or angle); and it must be kept in mind that the same difference is common to the sine and cosecant, to the tangent and cotangent, and to the secant and cosine. They are inserted for the convenience of finding the values of the sines and cosines, &c., of angles which are expressed in degrees, minutes, and seconds.

70. The above, as just stated, is the usual arrangement of most tables, but in the earlier editions of Norie and some other works the arrangement is somewhat different.

The columns are arranged thus:—

M	Sine.	Diff.	Cosine.	Diff.	Tangent.	Diff.	Cotangent	Secant.	Cosecant.	M
M	Cosine.	Diff.	Sine.	Diff.	Cotangent	Diff.	Tangent.	Cosecant.	Secant.	M

Since the same difference is common to the sine and cosecant, to the tangent and cotangent, in this arrangement, then, it must be particularly borne in mind, that the first "Diff." column (from the left) belongs to the first column of logarithms on the left hand of the page, and is also the "Diff." for the first column on the right of the page; that the second column of "Diff." (from the left) belongs to the second column of logarithms from either the right or left of the page; and that the third column of "Diff." belongs to the third column from either the right or the left, which may be otherwise expressed, thus:—A cosecant takes a sine "diff."; a secant takes a cosine "diff."; and cotangent takes a tangent "diff."

71. In the use of these Tables, as in that of the natural sines, two questions present themselves:—First, having given the angle in degrees, minutes, and seconds, required the log. sine, log. cosine, &c. Second, having given the log. sine, log. cosine, &c., required the value of the angle in degrees, minutes, and seconds.

72. When an angle is presented in degrees and minutes only, the tabular logarithm of its sine, tangent, &c., will be found (Table XXV, Norie, or Table 68, Raper) simply by inspection, according to the following:—

RULE XVIII.

1°. **If the angle or arc is less than 45°.** *Find the* page *having the given degrees at the* top, *and in the left hand marginal column find the* minutes, *then opposite the minutes, and in the column which is marked at the* top *with the name of the* ratio, *will be found the logarithm sought.*

2°. **If the angle be greater than 45°.** *Look for the* page *having the given degrees at the* bottom, *and find the* minutes *in the right-hand column; the logarithm of the proposed function of the angle will be found* opposite *the* minutes *in the column* marked *at the* foot *with the* name *of the* ratio *whose logarithm is sought.*

Examples.

Ex. 1. Find the log. sine of 37° 47′.

As the arc is *less* than 45°, by looking at the *top* of the table for the degrees (37°), and in the *first* column on the left for the minutes (47′), we find in the column having at its *top* the word sine, the figures 9·787232, which is the log. sine of the arc required.

Ex. 2. Find the log. tang. of 75° 34′.

Here, as the arc is *greater* than 45°, looking at the *bottom* of the table for the degrees (75°), and in the *last* or right-hand column for the minutes (34′), we find in the column having tang. at the *bottom* 10·589431, which is the log. tangent of 75° 34′.

Log. sine of	40° 4′	is	9·808669	Log. sine of	57° 5′	is	9·924001
Log. cosine of	21 38	,,	9·968278	Log. cosine of	79 51	,,	9·246069
Log. tangent of	84 13	,,	10·994466	Log. tangent of	21 50	,,	9·602761
Log. cotangent of	55 58	,,	9·829532	Log. cotangent of	27 45	,,	10·278911
Log. secant of	70 20	,,	10·472954	Log. secant of	44 59	,,	10·150389
Log. cosecant of	8 35	,,	10·826092	Log. cosecant of	69 54	,,	10·027291

Examples for Practice.

Take out the logarithms of the following trigonometrical ratios.

1. Log. sine 9° 10′
2. Log. cosec. 40 40
3. Log. cosine 12 48
4. Log. tang. 37 26
5. Log. cotang. 8° 25′
6. Log. sec. 43 1
7. Log. cos. 53 28
8. Log. sine 51 49
9. Log. sec. 60° 34′
10. Log. cotang. 79 19
11. Log. cosec. 45 45
12. Log. tang. 53 56

73. If the value of the angle be given in degrees, minutes, and seconds, we proceed by

RULE XIX.

1°. *Find from the table the sine, tangent, secant, cosine, &c., which corresponds to the degrees and minutes;* also *take out the number in the contiguous column headed* "Diff." *on the same line* (see Nos. 69 and 70, page 49).

2°. *Multiply the tabular difference* ("Diff.") *by the seconds, reject the last* two figures (always two) *of the product for the division by* 100, *and the remaining figures will furnish the proper correction for seconds.*

Note 1.—If the value of the two figures cut off is not less than fifty, one must be added to the first right-hand figure left.

3°. *If the required quantity be a sine, tangent, or secant,* add *the result to the last figures obtained in* 1°; *if it be a cosine, cotangent, or cosecant,* subtract.*

The result will be the required sine, tangent, secant, cosine, &c.

Note 2.—The process above is sufficiently accurate, unless for the sines and tangents of very small angles, and for the tangents and secants of angles very near 90°. When an angle of degrees, minutes, and seconds, and of less magnitude than 3°, occurs in calculation, neither the logarithmic sine nor the logarithmic tangent will be found very accurately from the ordinary Tables. In some books, as Hutton's "Mathematical Tables," a special Table is given, containing the logarithmic sines and tangents to every second in the first two degrees of the quadrant. By that Table we should find the correct log. tang. of 1° 25′ 45″ to be $\bar{2}\cdot3970503$, whereas by using the tab. diff. for 1° 25′ and 1° 26′ in the ordinary Table, we should get the less accurate result, $\bar{2}\cdot3970448$, because for such small angles, the successive tabular differences for one minute shows too rapidly a wide departure from equality. When an angle of degrees, minutes, and seconds, and within less than 3° of 90° occurs in calculation, we cannot, for the reason just stated, obtain very accurately from the ordinary Tables either the logarithmic or the natural tangent. Thus the true log. tang. of 88° 4′ 15″ is 1·6029497; but by the ordinary Tables we would get for the last three figures 552. Norie gives the log. sine and log. tang. to every *ten* seconds of the first two degrees of the quadrant, and Raper gives the log. sines to every second up to 1° 30′, and to every ten seconds up to 4° 30′.

Examples.

Ex. 1. Find the log. sine of 6° 36′ 27″.

Here, as the arc is less than 45°, by looking at the top of the Table for the degrees (6°), and in the first column on the left, marked M at the top, for the minutes (36′), we find in the column having at its *top* the word sine the figures 9·060460, which is the log. sine corresponding to 6° 36′. Now this log. being found in the first column on the left, the tabular difference must be taken out of the first "diff." column from the left. It will be noticed that there is no diff. exactly opposite to 36′, but between 36′ and 37′ will be found the diff. 1817, which multipled by the seconds (27″) gives 49059, and rejecting the two last figures from this product (for the division by 100) gives quotient 490, which being increased by 1, since the figures cut off exceed 50 (see Note 1, page 51) gives 491 as the correction of the logarithm for the seconds. The work will stand thus:—

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* In some Tables these differences are those due to 1 minute, or 60 seconds, and are got by simply subtracting the greater of the logarithms from the less. The difference d due to any small number (a) of seconds is found from such Tables by the proportion $60 : a :: D : d$, so that $d = \frac{Da}{60}$. But, as before observed, the differences usually given in the Tables are those due not to 60 seconds but to 100 seconds, so that in these Tables $d = \frac{Da}{100}$; and thus d is found somewhat more readily.

Log. sine 6° 36′ = 9·060460	Tab. diff. 1817
27″ gives + 491.	× 27
9·060951	12719
	3634
	490,59 = 491

Ans.: Log. sine 6° 36′ 27″ = 9·060951.

Ex. 2. Find the log. cosine of 13° 5′ 32″.

The log. cosine of 13° 5′ is 9·988578, and the tabular difference corresponding to the log. cosine of the given degrees and minutes is 50; this being multiplied by 32 (the given number of seconds), and pointing off *two figures* to the right, is 16 to be *subtracted*, because the cosine is a *decreasing* log.; therefore—

Log. cosine 13° 5′ = 9·988578	Tab. diff. 50
32″ gives − 16	× 32
9·988562	100
	150
	16,00
Ans.: Log cosine 13° 5′ 32″ = 9·988562	or 16

The parts for the seconds are subtracted in this instance, *being a colog.* (See Rule XIX, 3°).

Ex. 3. Find the log. tangent 72° 59′ 8″.

The log. tangent of 72° 59′ is 10·514209, and the tab. diff. corresponding to the given degrees and minutes is 753; this being multiplied by 8 (the number of seconds), and pointing off *two figures* to the right is 60, which is additive; thus:—

Log. tang. 72° 59′ 0″ = 10·514209	Tab. diff. 753
Parts for 8″ = + 60	8
Log. tang. 72° 59′ 8″ = 10·514269	60,24

Ex. 4. Find the log. cotangent of 73° 21′ 7″.

The log. cotangent of 73° 21′ is 9·475763, and the tab. diff. corresponding to the cotangent of the given degrees and minutes is 767; this being multiplied by 7 (the given number of seconds), and pointing off *two figures* to the right is 54, which is to be *subtracted* in this instance, beng a colog.

Log. cotang. 73° 21′ 0″ = 9·475763	$\frac{\text{(Tab. diff. 767)} \times 7}{100} = 53,69$
Parts for 7″ = − 54	or 54
Log. cotang. 73° 21′ 7″ = 9·475709	

The parts for the seconds are subtracted in this instance, *being a colog.* (See Rule XIX, 3°).

Ex. 5. Take out log. sine 1° 5′ 34″.

Here the angle whose log. sine is sought being less than 2°, it must, therefore, be taken out of the special part of the Table (see Table XXV, page 107, Norie). The next less angle to be found in the Table is 1° 5′ 30″, the log. sine of which 8·279941, and the corresponding tabular "Diff." (for 10″ in this part of the Table) is 1104, which multiplied by 4, the seconds over 30, gives 4416, and cutting off one figure from the right, for the division by 10, gives the correction 442, to be added to the logarithm taken out of the Table; thus the work stands as follows:—

Log. sine 1° 5′ 30″ = 8·279941	Tab. diff. 1104
Parts for 4 = + 442	4
Log. sine 1 5 34 = 8·280383	441,6
	or 442 nearly.

Ex. 6. Required the cosecant of 3° 7′ 21″.

Log. cosecant	3° 7′ 0″ = 11·264646	Tab. diff.	3857
Parts for	21 = − 810		21
Log. cosecant	3 7 21 = 11·263836		3857
			7714
			809,97

Ex. 7. Take out the cosine of 88° 20′ 46″. (See Table XXV, Norie, page 108). In the special part of the Table, at the bottom part, we get 88° 20′ 40″ (the next less angle), and the cosine opposite is 8·460761, and the corresponding tabular "Diff." (for 10″ in this part of the Table) is 729, which multiplied by 6, the seconds over 40″, gives 4374, and cutting off one figure from the right, for the division by 10, gives the correction 437 to be subtracted from the logarithm taken out of the Table; thus the work stands as follows:—

Log. cosine	88° 20′ 40″ = 8·460761	Tab. diff.	729
Parts for	6 = − 437		6
Log. cosine	88 20 46 = 8·460324		437,4
			or 437

74. For the functions of an angle between 90° and 180° we may take the same functions of its supplement; hence,

To find the logarithm of a trigonometrical ratio of an angle greater than 90°, we have the following

RULE XX.

Subtract the angle from 180° and look for the remainder, which is called its supplement in the Tables.

Examples.

Ex. 1. Find the log. sine of 110° 24′. Subtract it from 180°.

From	180°	00′	
Subtract	110	24	
Remainder	69	36	(Supplement).

Look for the log. sine of remainder (namely 69° 36′), which is 9·971870; or log. sine 110° 24′ = 9·971870.

Ex. 2. Find the log. secant of 95° 43′; also the log. cosecant of the same.

Subtracting 95° 43′ from 180° 0′ gives remainder 84° 17′, and look for the log. secant of 84° 17′, which is 11·001701; ∴ log. secant of 95° 43′ is 11·001701.

Again, look for the cosecant of 84° 17′, which is 10·002165; ∴ log. cosecant of 95° 43′ is 10·002165.

Ex. 3. Find the log. tangent of 128° 55′ 47″.

From 180° 0′ 0″ Subtract 128° 55′ 47″ (Remainder) = 51° 4′ 13″ (Supplement).

∴ Supplement of the given angle = 51° 4′ 13″.

Log. tangent	51° 4′ 0″ = 10·092664	Tab. diff.	431
Parts for	13 = + 56		× 13
Log. tangent	51 4 13 = 10·092720		1293
			431
			56,03
			or 56

∴ Log. tangent 128° 55′ 47″ = 10·092720. *Ans.*

75. But a *readier* way, and the better practical method, is to proceed as follows:—

RULE XXI.

Diminish the given angle by 90°, *and look out the* remainder *in the tables, observing that if the trigonometrical ratio have* "co" *prefixed to it* drop *the* "co," *but if it have not* "co," prefix it, *then find the logarithm corresponding to the new ratio and angle. Or,*

If A *denote any angle less than* 90°, *then*

For sine ....(90 + A) *take out*........ *cosine* A
„ *tangent*......(90 + A) ———......*cotangent* A
„ *secant* ......(90 + A) ———...... *cosecant* A
„ *cosine* ......(90 + A) ———.........., *sine* A
„ *cosecant* ....(90 + A) ———........ *secant* A
„ *cotangent*....(90 + A) ———...... *tangent* A

Obs.—This rule may easily be remembered by observing that to the sine, tangent, and secant, *co* is prefixed, while from the *co*sine, *co*secant, and *co*tangent, the *co* is dropped, and in each case the excess of 90° of the angle is used.

Examples.

Ex. 1. Find the log. cosine of 110°.

To find the log. cosine of 110°, or log. cosine (90 + 20), take out the log. sine 20° (*i.e.*, for 110° — 90°), which is 9·534052.

Ex. 2. To find the log. secant of 160° 12′, take out the *co*secant 70° 12′, which is 10·026465.

Log. cosine of	143° 24′	=	Log. sine	53° 24′ is	9·904617
Log. cosecant of	99 37	=	Log. secant	9 37 „	10·006146
Log. sine of	109 2	=	Log. cosine	19 2 „	9·975583

Ex. 3. Find the log. cosecant of 131° 45′ 19″.

Subtracting 90° from 131° 45′ 19″ = 41° 45′ 19″.

Log. cosecant 131° 45′ 19″ = log. secant 41° 45′ 19″.

Log. secant	41°45′ 0″ = 10·127228	Tab. diff.	188
Parts for	+ 19 = + 36		× 19
Log. secant	41 45 19 = 10·127264		1692
			188
			35,72

In this instance "co" is prefixed to the given trigonometrical ratio, then, according to rule, "co" is dropped, and the log. corresponding to the new ratio is taken out for the remainder resulting from the given angle when diminished by 90°.

Ex. 4. Required the log. tangent 99° 32′ 58″.

Log. tangent 99° 32′ 58″ = cotangent 9° 32′ 58″.

Log. cotangent	9°32′ 0″ = 10·774844	Tab. diff.	1288
Parts for	+ 58 = − 747		58
Log. cotangent	9 32 58 = 10·774097		10304
			6440
			747,04

76. In Raper the required logs. are given to every half minute, and, therefore, the required log. is to be taken out to the nearest less arc to that given; and adjoining it will be seen a column of "Parts," from which the correction for the remaining seconds is to be taken, and this correction is to be ***added*** if the log. taken out be a sine, tangent, or secant, but ***subtracted*** if it be a cosine, cosecant, or cotangent (that is, if the log. have *co* prefixed). See Note 2, page 46.

In most cases the parts are given in the adjoining column for every second up to 30″, but when the angle is small, or large, some are given for each second up to 10″. In this case, if the parts for a larger number of odd seconds than 10 are required, take them out in instalments. When the angle is very small, or very large, the parts are not calculated at all, but the difference for a half minute is given opposite to each logarithm. In this case multiply the given difference by the number of the odd seconds and divide by 30. The result will be the parts required.

EXAMPLES.

Ex. 1. Find log. sine 37° 19′ 51″.

Log. sine	37° 19′ 30″	=	9·782713
Diff. for	21	=	+ 58
Log. sine	37 19 51	=	9·782771

Ex. 2. Find log. cotang. 64° 53′ 39″.

Log. cotang.	64° 53′ 30″	=	9·670813
Diff. for	9	=	− 49
Log. cotang.	64 53 39	=	9·670764

Ex. 3. Find log. tang. 8° 32′ 18″.

Log. tang.	8° 32′ 0″	=	9·176224
Diff. for	10	=	143
	8	=	115
Log. tang.	8 32 18	=	9·176482

Ex. 4. Find log. cosine 83° 41′ 57″.

Log. cosine	83° 41′ 30″	=	9·040914
Diff. for	27	=	− 515
Log. cosine	83 41 57	=	9·040399

Diff. for	10″	=	191
Diff. for	10	=	191
Diff. for	7	=	133
Diff. for	27	=	515

Ex. 5. Find log. cosec. 3° 7′ 21″.

Log. cosec.	3° 7′ 0″	=	11·264646
Diff. for	21	=	− 812
Log. cosec.	3 7 21	=	11·263834

Diff. for 30″ = 1160
21
1160
2320
3,0)24360
Diff. for 21″ = 812

77. But for the purpose of lessening the labour of finding the log. sines and cosines in the case where the parts are not given, two other tables have been constructed (Tables 66 and 67).

Table 66 gives the logarithms of sines of small angles from 0° to 1° 30′, and the logarithms of cosines of large angles from 88° 30′ to 90° to each second. Table 67 gives the logarithms of sines of angles from 1° 30′ to 4° 31′ and the log. cosines of angles from 85° 29′ to 88° 30′ to every ten seconds. In Table 67 there are columns of "parts" by which the log. of the sine or cosine of an angle containing odd seconds may be found, and conversely. Each page of this Table is divided into six spaces by horizontal lines, and there are two columns of parts in each space. The left-hand column of parts is to be used when the angle is in the upper half of the space, and the right-hand column when it is in the lower.

EXAMPLES.

Ex. 1. Take out log. sine 1° 5′ 34″.

Log. sine 1° 5′ 34″ = 8·280383. *Ans.*

Ex. 2. Take out log. cosine 88° 43′ 57″.

Log. cosine 88° 43′ 57″ = 8·344790. *Ans.*

Ex. 3. Find log. sine 4° 26′ 18″.

$$\begin{array}{lrl} \text{Log. sine } 4^\circ 26' 10'' & = & 8{\cdot}888446 \\ \text{Diff. for } \quad 8 & = + & 216 \\ \hline \text{Log. sine } 4\ 26\ 18 & = & 8{\cdot}888662 \end{array}$$

In this instance the parts are taken from the right-hand column, because the angle, 4° 26′ 10″, is situated in the lower half of the space.

EXAMPLES FOR PRACTICE.

Required the log. sine, tangent, secant, cosine, cotangent, and cosecant, corresponding to the following arcs:—

1. 37° 49′ 14″
2. 56 54 17
3. 10° 10′ 6″
4. 1 49 47
5. 87° 28′ 45″
6. 1 0 40

Take out of the Table the following:—

7. Log. sine 2° 40′ 10″
8. Log. sine 170 30 30
9. Log. sine 1 49 47
10. Log. cosine 89 59 19
11. Log. cosine 88 40 56
12. Log. cosine 108 40 6
13. Log. tang. 1 8 7
14. Log. cotang. 3 7 8
15. Log. tang. 114 9 30
16. Log. cosec. 127° 30′ 40″
17. Log. cosec. 141 16 51
18. Log. sine 2 0 53*
19. Log. cotang. 89 23 37
20. Log. cosine 87 23 27
21. Log. cosine 88 50 29
22. Log. tang. 1 2 18
23. Log. sec. 101 8 7
24. Log. sine 110 11 18

78. If the value of the log. sine, log. cosine, &c., *i.e.*, the logarithm of a trigonometrical ratio, be given, and it is required to find the corresponding angle in degrees and minutes, we use

RULE XXII.

Look for the logarithm in the several columns of the table marked at the top *or* bottom *with the name of the given trigonometrical ratio, which being found exactly or the nearest, whether larger or smaller, to it, will give the degrees and minutes answering to the given logarithm, being careful to observe that when the* name *of the given ratio is found at the* top *of the table, then the* degrees *are to be taken from the* top *and the* minutes *from the* left-hand *marginal column; but if the* name *of the ratio is found at the* bottom *of the table, take the* degrees *from the* bottom *and the* minutes *from the* right-hand *side of the page.*

NOTE.—In using the Table *inversely*, for example, in searching for the angle which has 9·611294 for the logarithm of its sine, the student must not distinguish sine from cosine, nor tangent from cotangent, but must consider *sines* and *cosines* as one table, *tangents* and *cotangents* as one table, and must cast an eye on both, and get to 9·611294 as fast as he can. For want of this caution some beginners will turn over page after page until they come to 45°, and then back again to the very page that was first opened.

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* When the tabular difference is considerable, as in this instance, the log. is easier reduced from the log. of the nearest minute.

EXAMPLE.

EX. 1. Required the angle corresponding to the log. sine 9·729223.

In page 142, Table XXV, NORIE, under the word "Sine," and opposite 25′ in left-hand marginal column, are the exact figures, the degree (being sought at the head of the page, because the column in which the figures are found is named at the head) is 32°; therefore, the angle is 32° 25′.

If the angles for the cosine of the same logarithm be required, the degrees are found at the bottom, and the minutes in the right-hand column, and is 57° 35′ accordingly.

Log. sine	9·731009 = 32° 34′	Log. cosine	9·995555 = 8° 11′
Log. sine	9·871073 = 48 0	Log. cosec.	10·030380 = 68 45
Log. tang.	9·787036 = 31 29	Log. cotang.	10·508820 = 17 13
Log. tang.	10·047850 = 48 9	Log. cosine	9·718497 = 58 28
Log. sec.	10·043673 = 25 16	Log. cosec.	10·307885 = 29 29
Log. sec.	10·566325 = 74 15	Log. cotang.	11·197235 = 3 38

79. If the value of the log. sine, log. cosine, &c., be given, and it is required to find the corresponding angle in degrees, minutes, and seconds, we use

RULE XXIII.

1°. *Find in the Tables* (XXV, NORIE) *the next lower log. sine, log. cosine, &c., and note the corresponding degrees and minutes; also, take the number from the corresponding part of the adjoining column of "Diff."*

2°. *Subtract this from the given log. sine, log. cosine, &c., multiply the difference by* 100, i.e., annex two cyphers, *divide by the tabular difference, and consider the result as seconds.*

3°. *If the given value be that of a log. sine, log. tangent, or log. secant,* add *these seconds to the degrees and minutes found in* 1°; *if it be that of a log. cosine, log. tangent, or log. cosecant,* i.e., *if the log. have* CO *prefixed,* subtract.

The result will be the required angle.

NOTE.—If the given log. be a cosine, cosecant, or cotangent, we may seek out the next *greater* to the given log.: then proceed by 2° to find the seconds, which *add* to the degrees and minutes as found by 1°.*

EXAMPLES.

EX. 1. Given log. sine = 9·422195 (or $\bar{1}$·422195); find the angle.

We take out 9·421857, the log. sine of 15° 19′, as it is the logarithm *next less* than the given one, which we take, as the logarithms in the columns increase with the angle. The difference of these logarithms is 338, and if two cyphers be affixed to the difference, and the number then divided by 768, taken from the column of Diff. in Table, we have 44 for the number of seconds to be *added* to the degrees and minutes before taken out. The work will stand thus:—

Given log. sine 9·422195
Tab. log. sine next less 9·421857 = log. sine 15° 19′

Tab. diff. for 100″ = 768)·33800(44″ additional seconds.
3072

3080
3072

Therefore 9·422195 = log. sine of 15° 19′ 44″.

---

* By writing down the log. corresponding to the *next less angle in every case* the seconds are always *additive*, thus avoiding confusion as to their mode of application. (See Note, Rule XVII, page 47).

Ex. 2. Given log. cosine = 9·873242 (or $\bar{1}$·873242): find the angle.

Here we take out 9·873223, the log. cosine of 41° 41′, as it is the log. cosine in the Table next less than 9·873242. The difference between these two logarithms is 19; and if two cyphers be affixed to the difference we get 1900; whence 1900 divided by 187, the number from the column of "Diff." gives 10 for the number of seconds to be subtracted. Hence the required angle is 41° 40′ 50″. The work will stand thus:—

Given log. cosine 9·873242
Tab. log. cosine next less 9·873223 = log. cosine 41° 41′ $\quad \dfrac{19 \times 100}{187} = 10''$ *subtractive.*
19
Tab. diff. for 100″ = 187.

Therefore, 9·873242 = log. cosine of 41° 40′ 50″.

Or, proceeding according to Note, Rule XVII, page 47.

Given log. cosine 9·873242
Tab. log. cosine next greater 9·873335 = 41° 40′ (next *less* angle).

Tab. diff for 100″ = 187)9300(50″, nearly, *additive.*

∴ angle required = 41° 40′ 50″.

Examples for Practice.

Required the Angles (to the nearest second) the Log. Sine of which is:—

1. 9·741279
2. 9·926100
3. 8·707654
4. 8·600700
5. 9·500000
6. 9·909176
7. 7·456430
8. 9·999631
9. 9·900000
10. 8·462167

Find the Arc to the Log. Cosine of

1. 9·787140
2. 8·134758
3. 9·179726
4. 9·517232
5. 8·361861
6. 9·932338
7. 9·998970
8. 8·281485
9. 7·797520
10. 9·000000

Find the Arc to the Log. Secant of

1. 10·000765
2. 10·205665
3. 10·048398
4. 10·022719
5. 11·642535

Find the Arc to the Log. Cosecant of

1. 10·252208
2. 11·005231
3. 10·121000
4. 11·442539
5. 11·467931
6. 11·166007
7. 10·070362
8. 11·079003
9. 10·009000
10. 11·290123

Find the Arc to the Log. Tangent of

1. 10·000100
2. 10·287342
3. 8·961007
4. 11·276400
5. 8·297036
6. 9·716135
7. 11·282456
8. 11·060431
9. 8·668612
10. 8·258262

Find the Arc to the Log. Cotangent of

1. 11·197568
2. 8·327691
3. 8·272775
4. 8·460000
5. 12·069844

MISCELLANEOUS.

1. If sine A = ·432651, find log. sine A.
2. If tang. A = 3, find log. tang. A.
3. Given log. cos. A = 9·236713, find nat cos. A.
4. Given log. tang. 35° 20′ = 9·850593, find log. cotang. 35° 20′ without using any tables at all.
5. Find the log. cosec. 68° 45′ 24″ from the table of natural sines only.
6. Given log. sec. A = 11·024680, find nat. cos. A.
7. Given log. cosine A = 9·450981, find A (1) from a table of log. cosines, and (2) from a table of nat. cosines.

8. Given nat. sec. A = 2·005163, find A (1) from a table of nat. sines and cosines, and (2) secant from a table of log. secants.
9. Sine 36° × tang. 54° = ·654.
10. Find by the tables the angle whose sine is $\sqrt{\frac{7}{18}}$.
11. Given log. cot. A = 11·015627, find nat. cot. A.
12. Find nat. cot. 45° 18′ 17″ from the table of cotangents.
13. Find to the nearest second the angle whose sine is $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{6}$, and $\frac{188}{308}$.
14. " " tang. is $\frac{81}{26}$, $\frac{137}{346}$, and $\frac{177}{484}$.

60. It is also necessary to have a distinct conception of the limits to which the Trigonometrical Ratios tend when the angles become right-angles. The following are the Trigonometrical Ratios for the angles 0° and 90°:—

Sin.	0° = 0	Sin.	90° = 1
Cos.	0° = 1	Cos.	90° = 0
Tang.	0° = 0	Tang.	90° = ∞
Cot.	0° = ∞ *	Cot.	90° = 0
Sec.	0° = 1	Sec.	90° = ∞
Cosec.	0° = ∞	Cosec.	90° = 1

And the following, therefore, are the Logarithms of their Trigonometrical Ratios:—

Log. sin.	0° = — ∞	Log. sin.	90° = 0
Log. cos.	0° = 0	Log. cos.	90° = — ∞
Log. tang.	0° = — ∞	Log. tang.	90° = ∞
Log. cot.	0° = ∞	Log. cot.	90° = — ∞
Log. sec.	0° = 0	Log. sec.	90° = ∞
Log. cosec.	0° = ∞	Log. cosec.	90° = 0

61. When these values occur amongst others requiring to be added to or subtracted from them, the learner must be careful to remember *that the addition to* or *subtraction from them of finite numbers cannot alter them.* Hence the explanation of the results in the following:

EXAMPLES.

Ex. 1. Add together log. cot. 0° and log. sine 20°.

Log. cot. 0° = ∞
Log. sine 20° = 9·534032

Ans. ∞

Ex. 2. Add together log. cos. 90° and log. tang. 45°.

Log. cos. 90° = — ∞
Log. tang. 45° = 10·000000

Ans. ∞

Ex. 3. From log. cos. 0° take log. sine 62° 48′.

Log. cos. 0° = — ∞
Log. sine 62° 48′ = 9·949105

Ans. — ∞

Ex. 4. From log. tang. 21° 48′ 30″ take log. cot. 90°.

Log. tang. 21° 48′ 30″ = 9·602218
Log. cot. 90° = — ∞

Ans. ∞

62. In the event of a bad or obliterated figure in the table, it may be convenient to know that the tangents are found by subtracting the cosines from the sines, adding always 10, or the radius; the cotangents are found by subtracting the tangents from 20, or the double radius, and the secants are found by subtractting the cosines from 20, the diameter of a circle whose radius is 10.

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* This mathematical symbol is called *infinity*.

NAVIGATION.

SPHERICAL TRIGONOMETRY.

An acquaintance with the properties of the sphere being absolutely necessary for the nautical student we give the enunciations of the most important, but state the definitions at length for convenience of future reference.

Sphere. **Centre.** *A Sphere* is a surface, every point of which is equally distant from a fixed point within it; this fixed point is called the *Centre*. A sphere may be conceived to be generated by the revolution of a semicircle about its diameter, which remains fixed throughout the motion.

Radius. The straight line which joins any point of the surface with the centre is called a *Radius*.

Diameter. A straight line drawn through the centre and terminated both ways by the circumference is called a *Diameter*.

Section. Every *Section* of a sphere by a plane is a circle.

Great Circle. **Small Circle.** A *Great Circle* of a sphere is a section of the surface by a plane which passes through its centre. A *Small Circle* of a sphere is a section of the surface by a plane which does not pass through its centre.

All great circles of a sphere have the same radius. All great circles bisect each other.

Axis. The *Axis* of any circle of a sphere is that diameter of a sphere which is perpendicular to the plane of the circle.

Poles. The *extremities* of that diameter of a sphere which is perpendicular to the plane of a circle are called the *Poles* of the circle.

The poles of a great circle are equally distant from the plane of the circle.

Adjacent and Remote. The poles of a small circle are not equally distant from the plane of the circle. In the case of a small circle the poles may be distinguished as the *adjacent* and *remote* poles.

All parallel circles have the same poles. The distance of every point in the circumference of a circle from either of its poles is the same. The poles of a great circle are 90° distant from every point of the circle.

Co-ordinates.—A set of lines, angles, or planes, or combination of these, which, taken together, define the position of the several points of a given surface, or points in space. The method was invented by DESCARTES, the French geometer, who first expressed algebraically theorems involving the *position* of lines. To represent the position of a curve on a plane he chose a certain right line, to the different points of which he referred all the points of the given curve; then he chose a certain point in this line from which to commence the reckoning ("ad *ordiendum* ab es calculum.") Hence the series of lines by which the curve was referred to the chosen line were called *ordinates* (derived from a word of the same root, *ordinare*, to range in order), and the portions of the line "cut off" by this series, from the chosen point, were named *abscissæ* (*L'abscindere*, to cut off.) If, however, *two* lines are taken intersecting each other at a given angle in a fixed point, the several points of the curve in question may be referred to each of them in turn, and thus *two sets of ordinates* be contemplated which, *taken together*, define every point of the curve; hence the term *co-ordinates*.

Fig. 7.

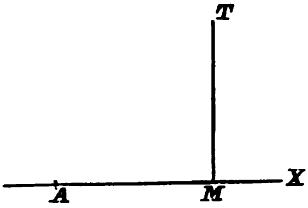


Fig. 8.

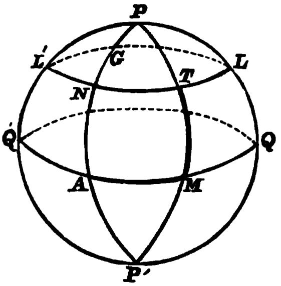
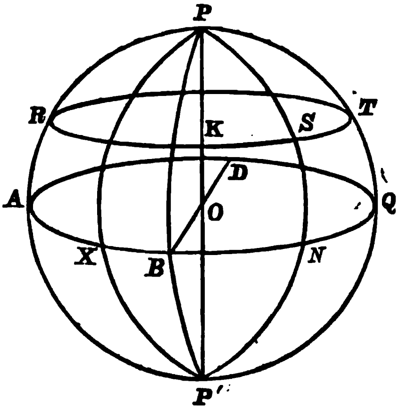


Fig. 9.



O is the centre of the sphere; O B and O D are Radii; P P′ and B D Diameters.

A B Q D is a Great Circle.

R S T is a Small Circle.

P P′ is the Axis of the circles A B Q D and R S T, and P P′ are the Poles of those circles; P is the Adjacent to R S T, P′ the Remote.

P B P′ and P N P′ are Secondaries to A B Q D.

B P N is a Spherical Angle measured by B N.

R S T is a Parallel to A B Q D.

X N and N S are spherical co-ordinates which determine the position of S with respect to the fixed Primary A B Q D and the fixed Secondary P X P′.

Primary Circles. Secondaries. Regarding any great circle as a *Primary* circle, all great circles which pass through its poles are called its *Secondaries*.

All secondaries cut their primary at right-angles.

Spherical Co-ordinates.

The position of a point on a sphere may be referred to any great circle and a fixed secondary by measuring its distance from them along the great circle and along the secondary which passes through the point. These distances are called the *Co-ordinates* of the point.

Spherical Angle.

The angle between two great circles is called a *Spherical Angle.*

Arc of a Great Circle—how measured.

The arc of a great circle is measured by the angle subtended by it at the centre of the sphere, which is also the same thing as the angle of inclination, at its pole, of two secondaries drawn through its extremities.

The two following propositions are necessary for the proper understanding of our subject, we, therefore, here introduce proof of them.

A great circle may be drawn through any two points of the sphere.

A great circle may be drawn through any two points on the surface of the sphere. For if these two points be joined by a straight line, and a plane in which this line lies be made to revolve about it till it meets the centre of the sphere, it is evident that this plane must then cut the sphere in a great circle which passes through the two points.

The shortest distance will be a curve in a plane, or, in other words, a circle; and of the indefinite number of circles which planes passing through the two points make with the surface of the sphere the great circle is the largest, and, therefore, its arc joining the two points has less curvature than the arc of any other circle joining them. Hence it most nearly approaches the chord, which is a straight line, and a straight line is the shortest distance in space between two points.

THE TERRESTRIAL SYSTEM.

The Primary Circle is the Equator.

The Secondary Circles are called Meridians,.

Co-ordinates, Latitude and Longitude (see above).

The first step in applying the principles above to the terrestrial sphere is to fix upon the primary great circle for the axis of co-ordinates. The question is decided by a physical characteristic of the earth, viz., its diurnal rotation, from which we get a *definite line*, itself immovable, as the primary one on which to base our definitions of the curves and points of the terrestrial sphere. The great circle whose plane is perpendicular to this fixed line is chosen as the primary circle for co-ordinates, on which are measured the abscissæ, and on secondaries to it are measured the ordinates of the various points on the earth's surface. The abscissæ are reckoned to the right and left of the initial position of the secondary or origin, and designated respectively east and west longitudes; and the ordinates are reckoned from the primary circle towards the poles of the primary, and designated respectively north and south latitudes. The initial secondary is variously chosen by different nations, usually their principal observatory, and is commonly called the first meridian. We are now in a position to give the following definitions.

Axis of the Earth.

The *Axis* of the earth is that diameter about which it revolves from west to east with a uniform motion.

Poles of the Earth. The *Poles* of the earth are the two extremities of the axis, distinguished respectively as the *North Pole* and the *South Pole*. The former being that to which we in Europe are nearest.

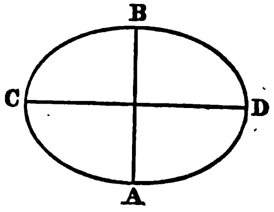
Equator. The *Equator* (called also the *Equinoctial*, and, by seamen, the *Line*) is a great circle on the surface of the earth, formed by a plane perpendicular to the axis of the earth and passing through its centre; and, therefore, dividing the earth into two equal parts, the northern and southern hemispheres.

Figure of the Earth. The earth is nearly a globe or sphere.

The ordinary proofs of this are of the following nature:—1st. When a vessel is seen at a considerable distance on the sea, in any part of the world, the hull is entirely or partly concealed by the water, though the masts are visible. 2nd. Ships have actually and repeatedly made the circuit of the globe; that is, by sailing from a port in a westerly direction they have returned to it in an easterly direction. 3rd. When we travel a considerable distance from north to south, a number of new stars appear, successively, in the heavens, in the quarter to which we are advancing, and many of those in the opposite quarter gradually disappear, which would not happen if the earth were a plane in that direction. 4th. In an eclipse of the moon, which is caused by the intervention of the body of the earth between the sun and moon, the shadow of the earth thrown on the moon is found in all cases, and in every position of the earth, to be a circular figure; the earth, therefore, which casts that shadow, must be a round body. 5th. Whenever a portion of the earth's surface is measured by triangulation, the sum of the three angles always exhibits an excess over two right-angles, which would not be the case if it were a plane, and not a sphere. This increase in measurement over two right-angles is called the spherical excess. 6th. If observations be made on different points on the surface of the earth, at some distance from each other, of the stars which are in the zenith at these various points, it will be found that the imaginary straight lines which join the point of observation with zenith are not parallel to each other, and the surface of the earth must, therefore, be a curved surface, and not a plane.

Exact Figure of the Earth. The earth, however, though very approximately a sphere, differs therefrom to an appreciable extent. It appears that the true figure of the earth is very nearly that of an oblate spheroid, that is, an ellipsoid generated by the revolution of an ellipse, A B C D, Fig. 10, about its minor axis A B. The section made by a plane through the earth's axis is nearly an ellipse, of which the major axis is the equatorial and the minor axis the polar diameter of the earth (the eccentricity of the ellipse is designedly much exaggerated in the figure).

Fig. 10.



The shortest diameter (that which joins the poles) being 7899 statute miles, and that at the fullest parts (about the equator) being nearly 27 more.

NOTE.—The *exact* form of the earth can only be determined by measurements and calculations of great precision, and is a subject which still engages the attention of scientific men. We can, of course, in a work like this, give no intelligible account of the refined mathematical processes by which the probable values of the flattening in, and the absolute dimensions have been obtained. It is generally believed that at some remote epoch the earth was in a fluid or semi-fluid condition. At the time that this was so the effect of the centrifugal force would make the earth bulge out at the equator and flatten it down at the poles, and thus impart to it the shape of an ellipsoid of revolution. The shortest axis of this ellipsoid would coincide with the axis of rotation. And this is proved by observations to be the case: the oscillations of a pendulum of a given length become more rapid as it is conveyed from the equator to either pole, proving that the force of gravity is increased, and, consequently, that the poles are nearer the earth's centre than the equator is. The measurement of the arcs of a meridian under different parallels furnishes another proof of the same fact; for it is found that the length of a degree of a meridian increases as the poles are approached, and, consequently, that the earth's surface must be flatter in that direction than elsewhere. The earth may, therefore, be defined to be a *spheroid of revolution*, and as the depression, or flattening, occurs at the poles, just as in an orange, it could be described in mathematical language as an *oblate* spheroid, in contradistinction to a *prolate* spheroid, or one which resembles an egg in being drawn out in the direction of the axis.

Accurate geodetical measurements show that there are deviations from the regular ellipsoid; in fact, the exact figure of the earth is now known not to be an exact ellipsoid of revolution; but it is sufficient for the purpose of nautical astronomy to assume all the meridians to be ellipses with the mean dimensions deduced from all the measures made in various parts of the world.

According to the most recent determinations by Col. CLARKE, R.E.,* we have the following dimensions of the ellipsoid of revolution which most closely approximates to the figure of the earth:—Let a b be the equatorial and polar semi-diameters respectively, then

$$a = 6378207 \text{ metres} = 20926062 \text{ feet},$$

$$b = 6356584 \text{ metres} = 20855121 \text{ feet},$$

while for the ellipticity,

$$e = \frac{a-b}{a} = \frac{1}{294.98}$$

The difference of this equatorial and polar radii, expressed in parts of the equatorial radius as unity, is called the *compression*,

$$\text{or, } c = \frac{a-b}{a} = 1 - \frac{b}{a}$$

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* *Geodesy*, by Col. A. R. CLARKE, C.B. (Clarendon Press Series, Oxford, 1880.)

Meridians.

Meridians are great circles on the surface of the earth, passing through the poles and cutting the equator at right-angles; and, therefore, secondaries to the equator.

They are called *Meridians* because they mark all places which have noon at the same instant. They also mark out all places which have the same longitude, and are hence called "*Circles of Longitude.*" The definition above is only correct if the earth is regarded as a sphere. If we take into account that the earth is an oblate spheroid, it must be replaced by the following:—Meridians are the sections of the earth's surface by planes passing through the two poles. These curves are ellipses, the major and minor axis of which are respectively the equatorial and polar diameter of the earth.

The Meridian of a Place.

The *Meridian* of a place on the surface of the earth is a great circle passing through the place and the poles of the earth; in other words, it is a section of the earth by a plane passing through the poles and the place.

The First Meridian.

The First Meridian is a fixed meridian, by reference to which the position of points on the earth are determined. The selection of the "*Initial Circle of Longitude,*" or, as it is more commonly called the "*First Meridian,*" is a matter of arbitrary choice amongst different nations; thus the first meridian is with us that of Greenwich, whilst the French use Paris, and other nations their principal national observatory.

Latitude.

The *Latitude of a Place* is the arc of the meridian intercepted between the equator and the place, reckoned in degrees (°), minutes (′), and seconds (″).

Latitude is reckoned north or south from the equator through an arc 0° to 90°.

If the earth had been a perfect sphere such measurement would have been made from its centre; but as it is not the measurement takes place from the intersection of a perpendicular let fall from the plane touching the plane with the equatorial axis of the earth. This is designated geographinal latitude, in contradistinction to the angular distance at the centre of the earth, measured on a meridian between the equator and any place, which angular distance is designated geocentric latitude.

Parallels of Latitude.

Parallels of Latitude are small circles formed by cutting planes parallel to the equator.

Co-Latitude.

Co-latitude is the complement of the latitude to 90°.

Difference of Latitude.

The Difference of Latitude between two places is the arc of a meridian included between their parallels of latitude.

The Difference of Latitude of the Ship is therefore the distance made good in a North and South direction. This is also called her "*Northing*" or "*Southing,*" these names being indicated by the initials N. and S.

Longitude of a Place.

The Longitude of a Place on the earth's surface is the arc of the equator intercepted between the first meridian and that passing through the place. Or, which is the same

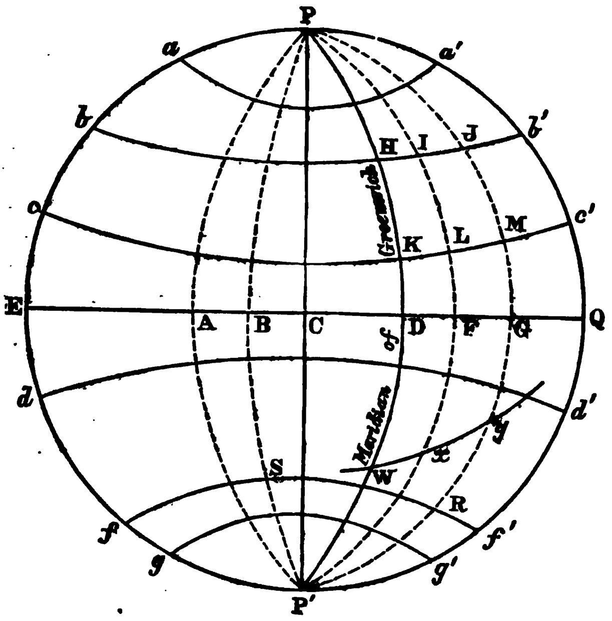
thing, it is the angle at the pole included between the first meridian and the meridian of the place.

Longitudes are reckoned from the origin—the intersection of the equator by the first meridian—eastward or westward, either in arc 0° to 180°, or in time 0^h to 12^h.

Difference of Longitude.

***The Difference of Longitude* between two places is the arc of the equator intercepted between their meridian; or which is the same thing, the corresponding angle at the poles.**

Fig. 11.



PP' is the Earth's Axis.

P and P' are the Poles of the Earth.

EQ is the Equator.

***aa'*, *bb'*, *cc'*, *dd'* are Parallels of Latitude.**

PAP', PBP', PDP', &c., are Meridians of which PDP' is taken for the First Meridian.

PIFP' is the Meridian of L.

DG is the Longitude of J. **DB is the Longitude of S.**

GJ is the Latitude of J. **BS is the Latitude of S.**

BG is the Difference of Longitude between J and S.

JR is the Difference of Latitude between J and S.

NAVIGATION.—DEFINITIONS.

Navigation is a general term denoting that science which treats of the determination of the place of a ship on the sea, and which furnishes the knowledge requisite for taking a vessel from one place to another. The two fundamental problems of navigation are, therefore, the finding at sea the present position of the ship, and the determining the future course.

The place of a ship is determined by either of two methods, which are independent of each other: 1st. By referring it to some other place, as a fixed point of land, or a previous defined place of the ship herself. 2nd. By astronomical observations.

It has been customary to employ the term NAVIGATION in a restricted sense to the first of these methods; the second is usually treated of under the head of NAUTICAL ASTRONOMY.

Navigation and Nautical Astronomy are the two great co-ordinate divisions of the "*Art of Sailing on the Sea*," as the old writers quaintly worded it. The first branch of the art is accomplished by means of the Mariner's Compass, which shows the direction of the ship's track; the Log, which, with the help of sand glasses for measuring small intervals of time, gives the velocity or the rate of sailing, and thence the distance run in any interval; and also a Chart of appropriate construction; in short this branch of the art relates to the directing the ship's course under the varying forces of winds and currents, and the estimation of her change of place. The second division is that branch of practical astronomy by which the situation of the observer on the globe is ascertained by a *comparison of the position of his Zenith with relation to the heavens with the known position of the Zenith of a known place at the same moment.* The principal instruments are the sextant for measuring the altitudes and taking the distances of heavenly bodies; and a chronometer to tell us the difference in time between the meridian of the ship and the first meridian; also a pre-calculated astronomical register, such as the Nautical Almanac, the Connaissance de Temps of France, &c. The solution of problems in nautical astronomy requires the use of spherical trigonometry, which is therefore characteristic of this method of navigation.

Horizon. *The Horizon* of a place is the small circle which bounds the view of the observer, being the circle where the earth (or sea) and sky seem to meet. This is called the *visible* or *sea horizon.*

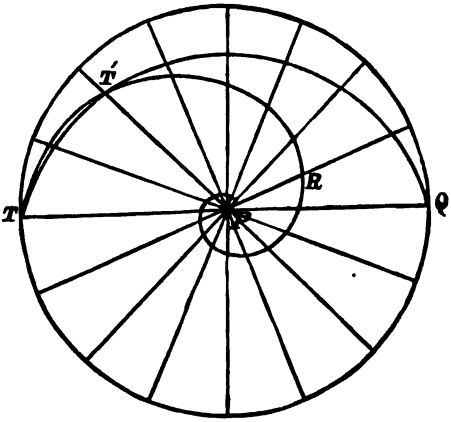
The meridian line of the spectator's station passes north and south through the centre of the horizon, cutting the circumference in the *north* and *south* points; a diameter drawn at right-angles to the meridian cuts the circumference in the *east* and *west* points. The horizon is thus divided into quadrants by the four cardinal points, north, east, south, and west, and each quadrant is sub-divided into eight equal parts by points which are named by a combination of the names of the cardinal points. The magnitude of each division is also spoken of as a point, and is equivalent to 11° 15′. The horizon is divided again according to the common method of dividing any circle, viz., into 360°, and in this case it is sometimes convenient to reckon from north or south through 180°, or from either of those points to the east and west points through 90°.

Rhumb. Any straight line drawn from the position of the spectator to the circumference of his horizon is called a *Rhumb.* Thirty-two of these have names assigned to them.

Rhumb Curve or Loxodromic Curve. The line connecting the several points of the earth through which a ship passes in succession while she sails without altering her course, is called a *Rhumb Line,* or

Loxodromic Curve. The Rhumb Line coincides with the meridian, when the course is due N. or S., or with a parallel of latitude when the course is due E. or W. On any other course but these the Rhumb Line is a spiral, approaching nearer and nearer to one of the poles at every convolution, but never reaching it. (See Fig. 12.)

Fig. 12.



Such a curve is appropriately called the *Equiangular Spiral*, and the *Loxodromic Curve;* and, also, because in sailing on it we keep on the same rhumb or point of the compass, it is called the *Rhumb Curve.* It is the track used ordinarily in navigation, for when out of sight of land the compass determines the ship's track, and hence the selection of that track which makes a constant angle with the meridian, the advantages of such a selection being that the seaman is not required to alter his course. It would seem desirable to take the shortest route on the voyage, and this is the arc of a great circle; but the great circle drawn between two places—except it happens to be on the equator, or a meridian itself—cuts successive meridians at different angles, as a little consideration will show. Our track will then generally be different from the great circle, and we define it by its essential property of cutting all the meridians at the same angle. Its form is a spiral which, if continued, will wind round the globe and approximate to the pole. Thus suppose for simplicity we start from a place T on the equator (Fig. 12) to sail to T′ lying to the North. Then the great circle, through T and T′ cuts the equator again in Q, but a track which cuts the successive meridians at the same angle, passing through T and T′ will take the course indicated in the diagram, continually approaching to the pole but never reaching it, TT′R. That such a curve may be drawn through any two given points will appear from this consideration,—that from one of the points an infinite number of these curves can be drawn, making different angles with the meridian, and on some one of these the second point must lie. It is evident also that only one of these curves can pass through the two points. When in sight of his port the compass is no longer needed, and the rhumb line is given up, and the port is made for on the great circle. When accurately following the compass course,

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we are, in strictness, only approximating, though very closely approximating, to a rhumb line, on account of the continuous change in the variation, due to the magnetic pole and the pole of the earth not being coincident.

Course. The *Course*, from one point of the earth's surface to another, is the constant angle which the rhumb curve joining the two points makes with the meridians, or it is the direction in which a ship sails from one place to another, this direction being referred to the meridian, which lies truly north or south, or to the north or south line of the compass by which the ship is steered. The former is distinguished as the *True Course*, the latter as the *Compass Course*.

True Course.

Compass Course.

The seaman is now in a position to define and describe the direction in which he is sailing at any particular moment, *e.g.*, S.W. by S., or S. 33° 45′ W., &c. He is also able to take this direction by the help of the magnet, which carries a card divided by rhumb lines, precisely similar to those marking the divisions of the horizon.

Distance. The *Distance* between two places is the arc of the rhumb line intercepted between them, expressed in nautical miles of 60 to the degree of latitude. Thus (Fig. 13, page 70) the length of the line A F, expressed in minutes of a great circle of the earth, is called the *distance*.*

This is always the sense in which the word "distance" is understood by the seaman, when standing alone, viz., the length of the ship's track when she sails on a constant course from the place of her departure to the place of her destination. It must never be lost sight of that the distance is not necessarily nor generally the *shortest* distance between the two places, that is, the distance as the "crow flies." On a Mercator's chart the rhumb curve is represented by a straight line, but it must be borne in mind that equal parts of any such line do not represent equal distances on the earth.

Shortest Distance. But the *Shortest Distance* between two places is the arc of the great circle which joins them.

Meridian Distance. The *Meridian Distance* between two places is the arc of a parallel of latitude intercepted between them.

Plane Sailing. *Plane Sailing* is the method of solving problems in navigation, on the assumption that although the path of a ship is on a *spherical surface*, yet the length of this path may be represented by a straight line on a *plane* surface, and that all the particulars necessary to be considered—longitude excepted—may be embodied in a plane triangle.

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* The reason of this is, that we must necessarily have a uniform unit of measurement, and this unit is conveniently chosen to be the length of a minute of arc of the great circle. *Minutes* of a great circle are usually called *nautical miles*, or simply miles.

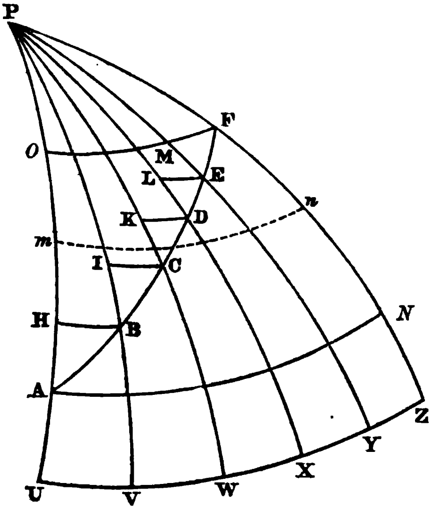
Plane sailing is usually defined to be the art of navigating a ship on the supposition that the earth is a plane. This definition is erroneous in the extreme: in all sailings the earth is regarded as what it really is—a sphere. All problems which involve only the course sailed by a ship, the distance made good, the difference of latitude, and another term called the departure which will be presently explained, are solved by the methods proper to right-angled plane triangles.

As a ship proceeds from one place to another, as from A to F (Fig. 13), at successive points she makes good a certain distance in the direction of the meridian, and a certain distance perpendicular to this. The distance sailed may then be resolved into two component distances in these several directions.

It is evident that in sailing from A to F (Fig. 13) the distance made good in the direction of the meridian, *i.e.*, North or South, is the difference of latitude of the two places—A O; but the distance made good perpendicular to the meridians is not so easily perceived, since at every successive moment it is reckoned (except the course is East or West) on the arcs of small circles constantly varying in magnitude. The element we are considering is called the *departure*, and is arrived at as follows:

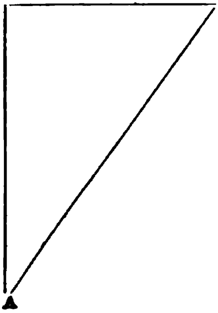
On the rhumb curve A F joining the two places A and F take a number of points equidistant from one another, commencing at A, B, C, &c., through these draw the meridians P B V, P C W, P D X, &c., and so close together that the intercepted portions AB, BC, CD, &c., may be regarded as straight lines: draw arcs of parallels of latitude from each point to the adjacent meridians B H, C I, D K, &c.

Fig. 13.



Now A B + B C + C D + &c., is the distance sailed from A to F on the course H A B; and A H + B I + C K + &c., is the difference of latitude A O between A, the place left, and F the place arrived at. Then if the points BH, CI, DK be taken *indefinitely* near each other, the sum of all these intercepts, or arcs of parallels of latitude, will be the distance made good perpendicular to all the intermediate meridians in passing from A to F corresponding to the sub-divisions of the rhumb line, and is called in nautical language the *departure*.

Fig. 14.



Let now a right-angled plane triangle, similar to the little right-angled triangle A H B, be constructed, that is, a right-angled triangle, in which A is the angle of the course, and let the hypothenuse A B represent the distance sailed, that is, the length of A F on the globe; then it is obvious that the perpendicular A C will represent the difference of latitude A O; while the base C B —the side opposite the course—will represent the sum of all the departures, H B, I C, K D, &c., from the successive meridians it crosses. This length C B is called the *departure* made by the ship in sailing from A to F: there is no line corresponding to it on the globe.*

In most cases which practically present themselves an approximation to the departure may be used, and it is obtained from a very simple consideration. If in the last figure we draw the arc of parallels between the meridians of A and F, A N in the latitude of A, F O in the latitude of F, it is evident that the departure between A and F is less than A *n′* and greater than F O. Bisect A O in *m* and draw *m n* the arc of the parallel between the meridians of A and F; then this arc *m n* is an approximation generally to the departure. It is evidently only an approximation as in the part of the figure A G F N between *m n* and O F adjacent to the pole, the meridians increase their inclination to each other more rapidly than in the other part between *m n* and

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* The right-angled triangle commonly employed in the solution of problems in plane sailing is merely a geometrical interpretation of the equation

Difference of latitude = distance × cosine course.

Thus, if A B is a line as long as the rhumb curve A F (Fig. 13), and A be equal to the course, A C must be equal to the difference of latitude for it is equal to

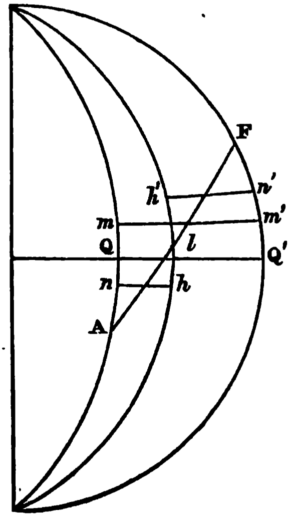
Distance × cosine course,

which is the necessary condition given by consideration of the sphere, B C is a consequence of this geometrical interpretation, and has no direct counterpart on the sphere—it is in fact an artificial line, the employment of which in the necessary calculations is, however, of great utility. It must not be supposed that the angle can be looked upon as a chart. The line A B does not represent the track actually sailed over by a ship, nor does the point B represent the position she arrives at at the end of her run upon the course represented by A. The parts of the triangle represent truly what has been stated and *nothing more*. It is sometimes stated that so far as the dist., diff. lat., dep., and course are concerned "the results are just the same as they would be if the ship were to sail on a plane surface instead of on a spherical surface," but such is not the case: for if the earth were a plane, and if B represented the position of the ship at the commencement of the run, A would represent the position of the ship at the end, which in consequence of the earth being spherical it does not, the true position at the end of the run being to the left of A, if B and A are both north of the equator.

A N adjacent to the equator. This is, however, only applicable when the two places lie on the same side of the equator; the method has to be modified when the two latitudes have different names.

When the places A and F are on different sides of the equator the middle latitude fails to give an arc of a parallel which is an approximation to the departure.

Fig. 15.



Let the rhumb line A F (Fig. 15) cut the equator in l, and let nh be the arc of the parallel of the half latitude of A intercepted between the meridians of A and l, and $n'h'$ the arc of the parallel of the half latitude A intercepted between the meridians of F and l. Then

nh is an approximation to the departure in sailing from A to l.
and $h'n'$ „ „ l to F.
∴ $nh + h'n'$ „ „ A to F.

Departure. The *Departure* is the distance, in nautical miles, made good due east or west in sailing on a rhumb line, and is marked east (E.) or west (W.), according as it is made towards the east or west, and such departure is expressed in *miles* and not, like longitude, in *arc*.

If a number of points be taken on the distance indefinitely near to one another, with meridians drawn through each of these points, the sum of all the arcs of parallels of latitude drawn through the points and intercepted between the meridians is called the departure.

Parallel Sailing. When a ship sails due East or West, her track is on a parallel of latitude and the case is one of *Parallel Sailing.*

Middle Latitude. The *Middle Latitude* between two places is the latitude of the parallel of which the arc intercepted between the meridians of these places is equal to the departure.

When the two places lie on the *same* side of the equator the middle latitude is the latitude of the parallel passing midway between them: its value is therefore half the sum of the latitudes of the two places, but if the two latitudes have *different* names the simple middle latitude is replaced by the two half latitudes of each of the places.

By a property of the sphere we know that the arc of a parallel of latitude included between two meridians is equal to the arc of the equator, included by them, multiplied by the cosine of the latitude.

If we take the arc of middle latitude as representing the departure, this gives us

$$\text{dep.} = \text{diff. long.} \times \text{cos. mid. lat.}$$

Mercator's Chart. *Mercator's Chart* is a projection of the globe upon a plane surface according to certain mathematical principles. All the meridians are represented by parallel straight lines meeting the parallels of latitude, which are also represented as straight lines, at right-angles. The distance between the meridians are made the same in all latitudes and everywhere equal to the difference of longitude; the degrees of latitude increase in length from the equator to the pole in the same proportion as the degrees of longitude decrease on the globe. That which constitutes the chief value of Mercator's Chart for the purpose of navigation is *that the angle which a straight line joining any two places on the chart makes with the meridian, is equal to that which the rhumb line joining the same two places on the globe makes with the meridian.*

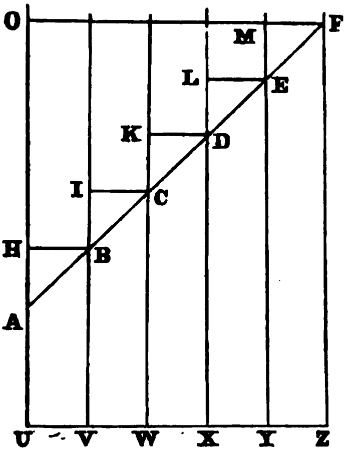
Meridional Parts. At the equator a degree of longitude is equal to a degree of latitude; but as we approach the poles, while (upon the supposition that the earth is a sphere) the degrees of latitude remain the same, the degrees of longitude become less and less. In the chart on Mercator's projection the degrees of longitude are made everywhere the same length, and, therefore, to preserve the proportion that exists at every part of the earth's surface between the degrees of latitude and the degrees of longitude, the former must be increased from their natural lengths more and more as we recede from the equator. The lengths of small portions of the meridians thus increased, expressed in minutes of the equator, are called meridional parts; and the *meridional parts for any latitude* is the line expressed in minutes (of the equator) into which the latitude is thus expanded.

Tables of Meridional Parts. The meridional parts computed for every minute of latitude from 0° to 90° form the *Table of Meridional Parts*, which is chiefly used for finding the meridional difference of latitude in solving problems in Mercator's sailing, and for constructing charts on Mercator's projection.

Meridional Difference of Latitude. *The Meridional Difference of Latitude* is the quantity which bears the same ratio to the difference of latitude that the difference of longitude bears to the departure. It is the projection of the difference of latitude on the Mercator's chart, and takes its name from the meridional parts, by the use of a table of which parts it is found.

Mercator's Sailing. *Mercator's Sailing* is the solution of the problems of navigation by means of the Table of *Meridional Parts*, and the chart constructed by means of it called *Mercator's Chart.*

Fig. 16.



Let A F represent the projected points A and F of the globe, Fig. 13, then A O is the projected or meridional difference of latitude, and O F or U Z the difference of longitude.

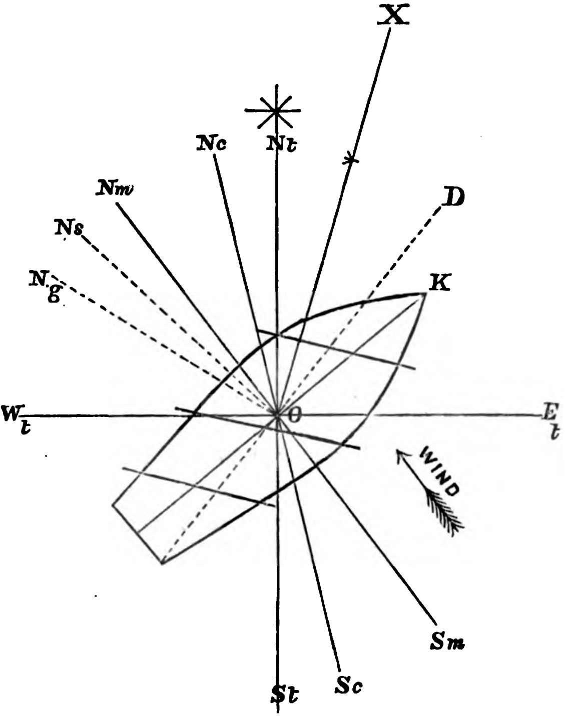
A O is composed of the elementary parts of the proper difference of latitude increased in the ratio of the secant of the latitudes, and is called the meridional difference of latitude.

The intermediate meridian distances are increased in the same ratio, and as each is thus made equal to the corresponding difference of longitude, their sum is equal to the whole difference of longitude O F, which therefore exceeds the sum of the intermediate meridian distances on the globe, in the same ratio that the sum of the meridional differences of latitude exceeds the proper difference of latitude.

The Meridians being represented as parallel straight lines, since the angles O A B, &c., which represent the course are equal, the rhumb line becomes a straight line.

Departure Course.	The *Departure Course* is the course which a ship would have made had she sailed from a particular point or headland, the bearing of which is taken before losing sight of land.
Leeway.	*Leeway* is the angle which the ship's wake makes with her keel.
Magnetic Meridian.	The *Magnetic Meridian* is the direction of the Compass Needle when it is unaffected by any local disturbing force. The Magnetic Meridian of a place is the vertical plane passing at this place through the two poles of a moveable magnetic needle in equillibrium about a vertical axis.
Variation.	The *Variation of the Compass* (called in scientific works the *Declination* of the needle) is the angle which the magnetic needle, under the influence of terrestrial magnetism only, makes with the meridian.
Deviation.	The *Deviation* of the compass is the angle between the magnetic meridian and the direction of the compass needle and represents the effect of the disturbing force of iron near it.
Compass Error.	The *Error of the Compass* is the angle between the meridian of the place and the direction of the compass needle.
Dip of the Needle.	The *Dip of the Needle* (called in scientific works the *Inclination*) is the angle between a freely suspended magnetised needle and the horizontal plane through the point of suspension.
True Course Steered.	The *True Course Steered* is the angle contained by the meridian and the direction of the ship's keel.
Magnetic Course Steered.	The *Magnetic Course Steered* is the angle contained by the magnetic meridian and the direction of the ship's keel.
Compass Course Steered.	The *Compass Course Steered* is the angle contained by the direction of the compass needle and the direction of the ship's keel.
Course Made Good.	The *Course Made Good* is the angle included between the meridian and the rhumb line passing through the place left, and the position arrived at.
True Bearing.	The *True Bearing* of an object or place is the angle contained between the meridian and the vertical plane which passes through the object and the observer.
Magnetic Bearing.	The *Magnetic Bearing* or *Correct Magnetic Bearing* of an object is the angle which its direction makes with the magnetic meridian.

Fig. 17.



N*t* o S*t* is the Meridian of the place or North and South line of the horizon.

N*m* o S*m* is the Magnetic Meridian, *i.e.*, the direction of Magnetic Needle, or the North and South line of the Compass Card when it is influenced only by Terrestrial Magnetism.

N*c* o S*c* is the Direction of the Needle in its position on board ship when under the attraction of iron in its vicinity.

N*t* o N*m* is the Variation (west in the figure).

N*m* o N*c* is the Deviation (east in the figure).

N*t* o N*c* is the Compass Error.

N*t* o K is the True Course steered.

N*m* o K is the Magnetic Course steered.

N*c* o K is the Compass Course steered.

D o K is the Leeway.

N*t* o D is the True Course made good.

N*m* o D is the Magnetic Course made good.

N*c* o D is the Compass Course made good.

N*t* o X is the True Bearing of X.

N*m* o X is the Magnetic Bearing of X.

N*c* o X is the Compass Bearing of X.

If a ship is sailing on a rhumb o N*s*

N*t* o N*s* is the True Course.

N*c* o N*s* the Compass Course (so far as the instrumental corrections go).

N*c* o N*g* the Compass Course made good.

N*s* o N*g* the Leeway.

The Correct Magnetic Bearing is the bearing which is observed with the Azimuth Compass after being corrected for deviation; from it the *true bearing* is deduced by applying the correction for variation.

A correct magnetic bearing, as given in "sailing directions" and on charts, is the correct magnetic bearing in respect to a compass not affected with deviation.

Compass Bearing. The *Compass Bearing* of an object is the angle contained by the direction of the compass needle, and the great circle which passes through the object and the observer, it is therefore affected by deviation and variation. If the correction for deviation is applied it becomes the correct magnetic bearing; and if, further, the correction for variation be applied, the true bearing or azimuth is deduced.

Taking a bearing of an object is technically called "*setting the object.*"

Cross Bearings. *Cross Bearings* are the bearings of the objects taken from the same place; the intersection of the lines of bearing fixing the point of observation on the chart.

Before the introduction of such large quantities of iron into the construction and equipment of steamers and iron sailing ships, bearings and courses were deemed to be sufficiently well defined when spoken of as true and magnetic—the latter qualifying term being used simply to indicate *the direction by compass as affected by variation only*, according to the locality. But on board an iron ship compass bearings and compass courses though magnetic—inasmuch as they are the indications of a magnetic needle—are no longer such in the old sense of the term, since they are affected by deviation. Under these circumstances it has been found necessary, especially in respect to this class of ships, to adopt a modification of the old nomenclature, and so "bearing" or "course" admits of an additional qualifying term not previously recognised, viz., *correct* magnetic.

PRELIMINARY RULES IN NAVIGATION.

83. Def.—The latitude and longitude of the place left are called the *latitude from* and *longitude from;* the latitude and longitude of the place arrived at are called the *latitude in* and *longitude in.*

84. Given the latitude from and latitude in or to, *to find the true difference of latitude.*

To find the **difference of latitude.** (For definition, &c., see page 65.)

RULE XXIV.

1°. When the **latitudes** have **like** names—*Subtract the less latitude from the greater, and multiply the degrees in the remainder by 60, adding in the minutes.* The result is the true difference of latitude.

2°. When the **latitudes** have **unlike** names—*Take the sum of the two latitudes, reduce it to minutes.* The result is the true difference of latitude.

3°. To name the diff. lat.—*If the* latitude to *is* North *of the* latitude from, *mark the diff. of latitude* North (N.); *but if* latitude to *is* South *of* latitude from, *mark diff. latitude* South (S.)

Note.—In naming the D. lat., since lat. is reckoned from the Equator (lat. 0°) towards the Poles (lat. 90° N. or S.), it follows that when a ship sails from a *low* to a *higher* lat. (of *like* names) the D. lat. must be of the *same* name as the lat. in; and when she sails from a *higher* to a *lower* lat. (of *like* names) the D. lat. made must be of a *different* name to the lat. in. But when the ship crosses the Equator the D. lat. will be N. to pass from South to North lat., and S. to pass from the Northern to the Southern hemisphere.

Examples.

Ex. 1. Find the diff. of lat. between Tynemouth Light, in lat. 55° 1′ N., and the Naze of Norway, in lat. 57° 58′ N.

Lat. Tynemouth	55° 1′ N.
Lat. Naze	57 58 N.
	2 57
	60
	177 N.

The lat. *from* (Tynemouth) and lat. *to* (Naze) being of the *same name*, that is, both North, the *difference* of them is taken for the diff. lat., and since we have to pass from a lower North lat. to a higher—the lat. *to* being North of the lat. *from*—the diff. lat. is marked North (N.)

Ex. 2. A ship from lat. 32° 40′ N., sails to lat. 20° 47′ N.: what is the diff. of lat. made?

Lat. from	32°40′ N.
Lat. to	20 47 N.
	11 53
	60
D. lat.	713 S.

The ship here passes from a *higher* N. lat. to a *lower* N. lat.—the lat. *to* being South of lat. *from*—and to do so must evidently sail S.; whence we mark diff. lat. S.

Ex. 3. Required the diff. of lat. between Cape Formosa, in lat. 4° 15′ N., and St. Helena, in lat. 15° 55′ S.

Lat. C. Formosa 4°15′ N.
Lat. St. Helena 15 55 S.

20 10
60

D. lat. 1210 S.

The lat. *from* (C. Formosa) is *North*, and the lat. *to* (St. Helena) is *South*, it is evident that the ship must sail South in order to pass from North lat. into South; whence we put South (S.) to the diff. of lat.

Ex. 4. Required the diff. of lat between Port Natal, in lat. 29° 53′ S., and Akyab, in lat. 20° 8′ N.

Lat. Port Natal 29°53′ S.
Lat. Akyab 20 8 N.

50 1
60

D. lat. 3001 N.

As Port Natal is in S. hemisphere and Akyab is in the N. hemisphere, to pass from the former into the latter the ship must sail N.

Ex. 5. A ship from lat. 50° S. arrives in lat. 45° 29′ S.: what is the diff. of lat?

Lat. from 50° 0′ S.
Lat. in 45 29 S.

D. lat. 4 31 = 271 N.

Here the ship passes from a *higher* to a *lower* S. lat., and to do so must evidently sail N.; whence the diff. lat. is marked N.

Ex. 6. A ship from lat. 13° 45′ S., arrives in lat. 26° 15′ S.: required diff. lat.

Lat. from 13°45′ S.
Lat. in 26 15 S.

12 30 = 750 S.

Here the ship passes from a *lower* to a *higher* S. lat, and to do so must evidently sail S.: whence S. is marked against the diff. of lat.

(*a*) When one of the places has no latitude, or is on the Equator, the latitude of the other place is equal to the difference of latitude.

Ex. 7. A ship from a place A, lat. 0, is bound to a place B, lat. 25° S.: required the diff. lat.

Since lat. is reckoned from the Equator lat. 0° (N. or S.), to pass from 0° to 25° S., the ship must evidently sail S.; whence the lat. of B (25°) is diff. of lat. and is marked S.

Ex. 8. A ship from a place A, in lat. 10° N., arrives at a place B, in lat. 0°: required the diff. lat. made.

One place being on the Equator, and the other in 10° N., the diff. of lat. is evidently 10° or 600′, and is named S., because it is evident the ship must sail South to pass from 10° N. to 0° N.

EXAMPLES FOR PRACTICE.

Required the difference of latitude between the place A and the place B in each of the following examples:—

1. Lat. A 55° 0′ N.
   B 58 23 N.
2. Lat. A 50°38′ N.
   B 42 48 N.
3. Lat. A 58°24′ S.
   B 63 17 S.
4. Lat. A 3 42 S.
   B 1 48 N.
5. Lat. A 13 15 S.
   B 0 0
6. Lat. A 0 0
   B 2 37 S.
7. Lat. A 10 10 N.
   B 0 0
8. Lat. A 49 52 S.
   B 42 13 S.
9. Lat. A 0 17 S.
   B 1 17 N.

85. To find the **meridional difference of latitude,** having given the latitude from and latitude in. (For definition, see page 74.)

RULE XXV.

Take the meridional parts for the two latitudes from the Table of Meridional Parts; take the difference *if the latitudes are of the* same name, *but their* sum *if the names are* unlike.

The result is the meridional difference of latitude.

EXAMPLES.

Ex. 1. Lat. A 49° 10′ N., lat. B 27° 40′ N.: find the mer. diff. of lat.

Lat. A	49° 10′ N.	M. parts	3397
B	27 40 N.	„	1729
		Mer. d. lat.	1668

Ex. 2. Lat. left 49° 58′ S., and lat. bound to 31° 42′ S.: find mer. diff. of lat.

Lat. left	49° 58′ S.	M. parts	3471
Lat. to	31 42 S.	„	2078
		Mer. d. lat.	1393

Ex. 3. Lat. left 29° 53′ S., and lat. to 20° 8 N.: required mer. diff. of lat.

Lat. left	29° 53′ S.	M. parts	1880
Lat. to	20 8 N.	„	1234
		Mer. d. lat.	3114

Ex. 4. Lat. from 46° 40′ N., and lat. to 34° 22′ S.: find the mer. diff. of lat.

Lat. left	46° 40′ N.	M. parts	3173
Lat. to	34 22 S.	„	2198
		Mer. d. lat.	5371

EXAMPLES FOR PRACTICE.

Find the meridional difference of latitude in each of the following examples:

1.	Lat. from 34° 40′ N.	Lat. in 33° 20′ N.	4.	Lat. from 15° 44′ N.	Lat. in 4° 20′ S.
2.	„ 24 12 S.	„ 15 18 N.	5.	„ 60 20 S.	„ 67 10 S.
3.	„ 49 10 S.	„ 52 47 S.	6.	„ 0 0	„ 4 20 N.

86. To find the **latitude in,** having given the latitude from (left) and true difference of latitude.

RULE XXVI.

1°. When the **latitude from** and true **difference of latitude** have a **like** name—*To the latitude from* add *the true difference of latitude (turned into degrees, minutes, and seconds, if necessary): the* sum *will be the* latitude in, *of the* same *name as the* latitude from.

2°. When the latitude from and true difference of latitude have *unlike* names—*Under the latitude* from *put the true difference of latitude (in degrees and minutes, if necessary): the* remainder *marked with the name of the* greater *is the* latitude in.

NOTE.—In order to remember these Rules, observe that when a ship is receding from the Equator she is getting to a *greater* latitude, and when approaching it to a less. In the former case we add the difference of latitude, and in the latter subtract it.

EXAMPLES.

Ex. 1. A ship from a place A in latitude 54° 20′ N., sails North until the diff. lat. is 135 miles: find the latitude in.

D. Lat.		
6,0)135	Lat. from	54° 20′ N.
	D. lat.	2 15 N.
2° 15′	Lat. in	56 35 N.

In this example the ship being in North latitude and having gone 2° 15′ to the North, has consequently *increased* her distance from the equator; hence D. lat. is added to the lat. left to find the lat. in.

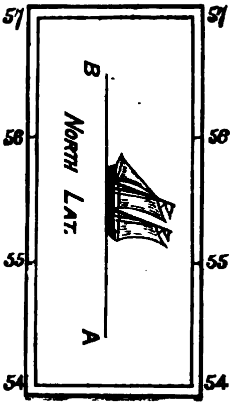


Fig. 18.

Ex. 2. A ship from a place A in latitude 31° 50′ S., sails North until the diff. lat. is 234 miles: required the lat. arrived at.

D. Lat.		
6,0)23,4	Lat. from	31° 50′ S.
	D. lat.	3 54 N.
3 54	Lat. in	27 56 S.

In this example the ship was in South latitude and has made 3° 54′ diff. lat. to the North; and consequently neared the equator by that number of miles, and *diminished* her South latitude (see Fig. 19).

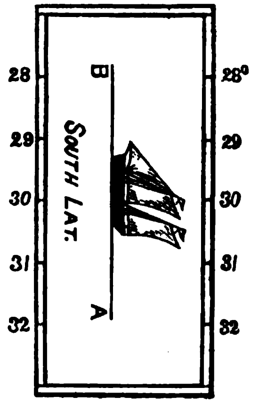


Fig. 19.

Ex. 3. A ship from a place A in latitude 2° 25′ N. makes 250 miles diff. lat. (southing): what lat. is she in?

D. Lat.		
6,0)25,0	Lat. from	2° 25′ N.
	D. lat.	4 10 S.
4 10	Lat. in	1 45 S.

In this example the diff. lat. 4° 10′ South is *greater* than the lat. left, which was North; the ship has, therefore, crossed the equator, and changed the *name* of her lat. to South (see Fig. 20).

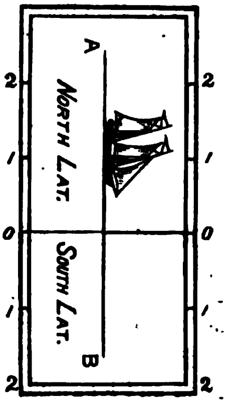


Fig. 20.

Ex. 4. A ship leaves a place A on the equator and sails South 120 miles: what lat. is she in?

D. Lat.		
6,0)12,0	Lat. from	0° 0′
	D. lat.	2 0 S.
2 0	Lat. in	2 0 S.

In this example the ship has made 120 miles (2° 0′) diff. lat. South, the whole of which was from the equator itself, and, therefore, the lat. arrived at is the same as the D. lat. (see Fig. 21).

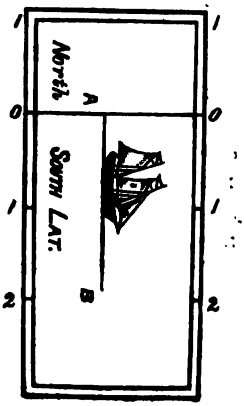


Fig. 21.

EXAMPLES FOR PRACTICE.

Find the latitude in in each of the following examples :—

1.	Lat. from	31°10′ N.	D. lat.	172′ N.	5.	Lat. from	0° 8′ N.	D. lat.	182′ S.
2.	„	29 38 N.	„	104 S.	6.	„	3 58 N.	„	238 S.
3.	„	2 56 S.	„	357 N.	7.	„	4 48 S.	„	288 N.
4.	„	0 0	„	168 S.	8.	„	35 25 S.	„	229 S.

87. To find the **middle latitude,** having given the latitude from and latitude in. (For definition see page 73.)

RULE XXVII.

The names being supposed *alike*, that is, both *North* or both *South—Add together the two latitudes, and* take *half the sum ; the result is the middle latitude.*

NOTE.—When the names are unlike, the middle latitude (which is seldom required but for obtaining the departure) should be found by means of a table; but in this case it may perhaps be as well to avoid the use of the middle latitude in any of the common problems of navigation.

EXAMPLES.

Ex. 1. Find the mid. lat., having given the lat. from 50° 25′ N., and lat. in 47° 12′ N.

Lat. from 50°25′ N.
Lat. in 47 12 N.
2)97 37
Mid. lat. 48 48

Ex. 2. Lat. from 6°28′ S., lat. in 14°50′ S.: required the mid. lat.

Lat. from 6°28′ S.
Lat. in 14 50 S.
2)21 18
Mid. lat. 10 39

EXAMPLES FOR PRACTICE.

Required the middlè latitude in each of the following examples :—

1.	Lat. from	16°10′ S.	D. lat.	138′ S.	4.	Lat. A	63°53′ S.	Lat. B	59°10′ S.
2.	„	1 40 S.	„	61 S.	5.	„	56 10 N.	„	50 15 N.
3.	„	36 22 N.	„	90 S.	6.	„	67 20 S.	„	61 42 S.

88. To find the **difference of longitude,** having given the longitude from and longitude to. (For definition see page 66.)

RULE XXVIII.

1°. When the longitudes are of the **same name**—*Take their difference and reduce the same to minutes, place* E. *or* W. *against the remainder, according as the longitude* to *is East or West of longitude* from.

2°. When the longitudes are of **contrary names**—*Take the* sum *of the two longs., which* sum, *if* less *than* 180°, *is the diff. of long., and attach* E. *or* W., *according as the long.* to *is East or West of long.* from; *but when the* sum exceeds 180° subtract *it from* 360°, *for the diff. of long., and reduce the remainder thus found to minutes, attaching to it the* contrary name to that *found in the usual way.*

NOTE.—Since longitude is reckoned from the meridian of Greenwich (long. 0°) East or West to long. 180°, it follows that to *pass* from a *less* to a *greater* long. (both longitudes of *like* name) the D. long. must be of the *same* name as long. in; and to sail from a *greater* to a *less* long. (both of *same* name) the D. long. must be of a *different* name from the long. in. But when a ship has to cross the meridian of Greenwich the D. long. must be East to pass into long. E. and West to pass into W. long. Also, when about to cross the meridian of 180°, if the ship is in E. long., the D. long. must be East to pass into W. long.; and if the ship is in W. long. the D. long. must be West to pass into E. long.

EXAMPLES.

Ex. 1. A ship from long. 5° 12′ W. is bound to a port in long. 90° W.: what diff. of long. must she make?

Long. from	5°12′ W.
Long. to	90 0 W.
	84 48
	60
D. long.	5088 W.

The ship here passes from a *less* to a *greater* W. long.; and therefore the diff. of long. must be W. to do so—the long. *to* being W. of long. *from*.

Ex. 2. Find the diff. of long., having given the long. from 89° 42′ W., and long. to 79° 42′ W.

Long. from	89°42′ W.
Long. to	79 42 W.
	10 0
	60
D. long.	600 E.

The long. *to* is *less* than long. *from*—the ship here passes from a *high* W. long. to a *lower*, and diff. long. must be E. to do so.

Ex. 3. A ship from Cape Bajoli, long. 3° 48′ E., is bound to Cape Sicie, in long. 5° 51′ E.: required the diff. of long.

Long. Cape Bajoli	3°48′ E.
Long. Cape Sicie	5 51 E.
	2 3
	60
D. long.	123 E.

The long. *to* (Cape Sicie) is E. of long. *from* (Cape Bajoli), therefore, diff. of long. is marked E. The ship must evidently sail E. to pass from a *low* E. long. to a *higher* E. long.

Ex. 4. A ship from long. 165° E. is bound to a place in long. 72° 12′ E.: what diff. of long. must she make?

Long. left	165° 0′ E.
Long. to	72 12 E.
	92 48
	60
D. long.	5568 W.

The ship in this example sails from a *greater* to a *less* long. (E. long.)—the long. *to* being W. of long. *left*—the diff. long. is therefore of a different name to the long. left.

Ex. 5. Required the diff. of long., having given the long. in 12° 20′ E., and long. to 2° 45′ W.

Long. in	12°20′ E.
Long. to	2 45 W.
	15 5
	60
D. long.	925 W.

Here the long. *to* is evidently W. of long. *in*, and the ship passes from E. long. to W. long., and in order to do so diff. long. must be W.

Ex. 6. A ship from Tynemouth, in long. 1° 25′ W., is bound to long. 7° 12′ E.: required the diff. of long.

Long. from	1°25′ W.
Long. to	7 12 E.
	8 37
	60
D. long.	517 E.

The ship here is about to cross the meridian of Greenwich (long. 0°) and pass from W. long. to E. long., whence the diff. of long must be E. to do so.

Ex. 7. Find the diff. long. between Acapulco, long. 99° 54′ W., and Pellew Island, long. 134° 21′ E.

Long. Acapulco	99°54′ W.
Long. Pellew Island	134 21 E.
Being greater than 180°	234 15 E.
it is subtracted from	360 0
Diff. of long. is	125 45 W.
	60
D. long.	7545

By going E. and W. from Greenwich, the two places in this example will be found to be 234° 15′ asunder, but as both places are for our purpose upon one circle, the smaller arc of the circle must be taken to find how far apart the places Acapulco and Pellew Island are separated; so that the sum 234° 15′ is subtracted from 360°, the whole circumference of a circle, for the required answer.

Ex. 8. A ship from long. 177° 50′ E. arrives in long. 178° 10′ W.: what diff. of long. has she made?

Long. left	177°50′ E.
Long. in	178 10 W.
Being greater than 180°	356 0 W.
it is subtracted from	360 0
Diff of long. is	4 0 E.
	60
D. long.	240 E.

The ship being in East long. and about to cross the meridian of 180°, the D. long. must be East to pass into W. long.

EXAMPLES FOR PRACTICE.

Required the difference of longitude between a place A and a place B in each of the following examples:—

1.	Long. A 9°29′ W.	Long. B 4°29′ W.	7.	Long. A 0°55′ E.	Long. B 7° 3′ E.
2.	„ 1 25 W.	„ 7 2 E.	8.	„ 40 10 E.	„ 33 10 E.
3.	„ 6 11 E.	„ 5 45 W.	9.	„ 178 30 W.	„ 178 30 E.
4.	„ 0 0	„ 4 20 W.	10.	„ 176 34 E.	„ 176 34 W.
5.	„ 4 20 W.	„ 0 10 E.	11.	„ 38 32 W.	„ 8 43 E.
6.	„ 7 2 E.	„ 0 0	12.	„ 5 12 W.	„ 25 12 W.

89. To find the **longitude in,** having given the longitude from (or left) and the difference of longitude.

RULE XXIX.

1°. When the longitude from and the difference of longitude have **like names**—*To the longitude from* add *difference of longitude (turned into degrees, if necessary): the* sum, *if not* more *than* 180°, *will be the* longitude in, *of the* same *name as the* longitude from; *but if the* sum exceed 180°, subtract *it from* 360°, *and the remainder is the long. in and of a contrary* name to long. from.

2°. When the longitude left and difference of longitude have **unlike names**—*Under* longitude from *put difference of longitude (in degrees and minutes, if necessary); take the* less *from the* greater; *the* remainder, *marked with the name of the* greater, *is the* longitude in.

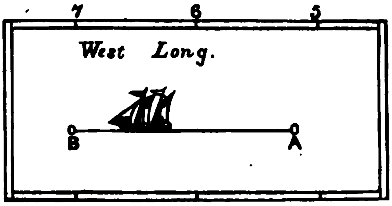
NOTE.—If the ship is receding from the first meridian, her longitude is evidently getting *greater;* if approaching it, *less.*

EXAMPLES.

Ex. 1. A ship from a place A in long. 5° 12′ W. makes 113 miles diff. long. West: required the long. arrived at.

D. Long.			
6,0)11,3	Long. from	5° 12′	W.
	D. long.	1 53	W.
1 53	Long. in	7 5	W.

Fig. 22.

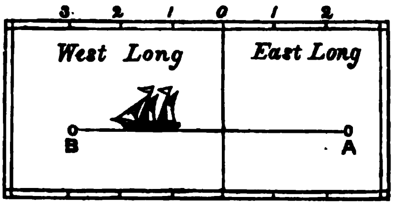


In this example the ship from a place A in W. long. has made 113 miles diff. long. *West,* and, consequently, increased her *West* long. by 1° 53′ (see Fig. 22).

Ex. 2. A ship from a place A in long. 2° 30′ E. makes 330 miles diff. long. West: find the long. arrived at.

D. Long.			
6,0)33,0	Long. left	2° 30′	E.
	D. long.	5 30	W.
5 30	Long. in	3 0	W.

Fig. 23.

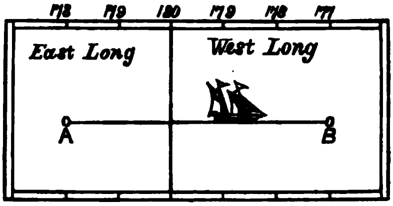


In this example the ship from a place A in long. 2° 30′ E. has made 5° 30′ diff. long. West, and thereby crossed the meridian of Greenwich, having run from East into West longitude (see Fig. 23).

Ex. 3. A ship from a place A in long. 178° 2' E. has made 298 miles diff. long. East: required the long. arrived at.

D. Long.			
6,0)29,8	Long. left	178° 2'	E.
	D. long.	4 58	E.
4 58	Exceeds 180°	183 0	E.
	Subt. from	360 0	
	Long. in	177 0	W.

Fig. 24.



In this example the ship has gone from East into West longitude, and by crossing the meridian of 180° has changed the *name* of her longitude from East to West (see Fig. 24).

Ex. 4. A ship from a place A in long. 174° 4' W. makes 797 miles diff. long. to the West: required the longitude arrived at.

6,0)79.7	Long. from	174° 4'	W.
	D. long.	13 17	W.
13 17 W.			
	Exceeds 180°	187 21	W.
	Subt. from	360 0	
	Long. in	172 39	E.

In this example the ship has gone from West long. to East, and by crossing the meridian of 180° has changed the *name* of her longitude from West to East.

Ex. 5. A ship from a place A on the meridian of Greenwich makes 178 miles diff. long. to the East: required the long. in.

6,0)17,8	Long. from	0° 0'	
	D. long.	2 58	E.
2 58			
	Long. in	2 58	E.

In this example the ship left the meridian of Greenwich, and has since made 2° 58' diff. long. away from it to the East; hence the long. arrived at is equal to the diff. long.

Examples for Practice.

Required the longitude in, or arrived at, in each of the following examples:

	Long. from	D. long.		Long. from	D. long.
1.	5° 48' W.	110' W.	7.	41° 29' W.	139' E.
2.	0 59 W.	137 E.	8.	94 4 E.	115 W.
3.	29 10 E.	114 E.	9.	98 54 E.	302 E.
4.	3 10 E.	220 W.	10.	178 13 E.	201 E.
5.	2 47 W.	242 E.	11.	177 6 W.	237 W.
6.	3 12 E.	237 W.	12.	179 59 W.	2 W.

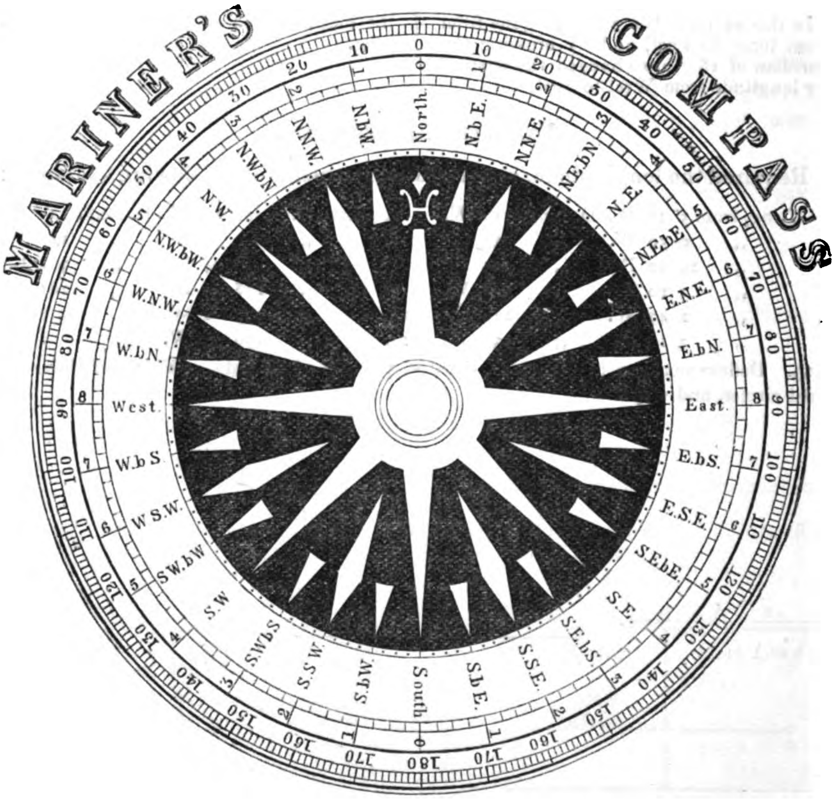
13. Define meridian of the earth, equator, parallel of latitude. Which of these are great circles, and why?

THE COMPASS.

90. The Compass* is simply an instrument which utilises the directive power of the magnet. A magnetised bar of steel, apart from disturbing forces and free to move, points in a definite direction, and to this direction all others may be referred, and a ship guided on any desired course.

There are various adaptations of the instrument, according to the use it is specially intended for. The compass intended for use on board ship is called the "**Mariner's Compass,**" and according to the purpose it is intended for it is named the **Steering Compass,** the **Standard Compass,** and the **Azimuth Compass.**

91. The **Mariner's Compass** consists of a circular card, which represents the horizon of the observer; the circumference or edge of the card being divided according to two systems of notation into points and degrees.



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* The origin of the compass is very obscure. The ancients were aware that the loadstone attracted iron, but were ignorant of its directing property. The instrument came into use in Europe sometime in the course of the thirteenth century.

(1.) **By Points.**—There are 32 *points;* and each of those divisions is again sub-divided into four parts called *quarter points.* A point of the compass being therefore the 32nd part of the circumference of a circle is equal to 11° 15′. The four principal points, or, as they are called, the *cardinal points,* are the North (represented by N.), South (S.), East (E.), West (W.), the East being to the right, and West to the left, when facing the North.

All the points of the Compass are called by names composed of these four terms.

Thus, the points half way between the cardinal points are called after the two adjacent cardinal points; hence the point midway between the North and East is called North-east, and represented by N.E.; so midway between South and East is called South-east (written S.E.); in like manner we get South-west (written S.W.), and North-west (written N.W.)*

A point half-way between one of these last and a cardinal point is called, in like manner, by a name composed of the nearest cardinal point and the adjacent points, N.E., N.W., S.E., and S.W. Thus, the point half-way between N. and N.E. is called North-north-east (written N.N.E.); the point between E. and N.E. is called East-north-east (written E.N.E.); and so we have E.S.E., S.S.E., S.S.W., W.S.W., W.N.W., and N.N.W. The points next the eight principal points, namely, N., N.E., E., S.E., S., S.W., and N.W., are named by placing *by* between the letter representing the point to which it is adjacent and the next cardinal point in the same direction. Thus, the point next to N., on the east side, is called North by East, *i.e.*, North in the direction towards East (written N. by E.); that next N.E., towards the North, is called North-east by North (N.E. by N.), *i.e.*, North-east in the direction towards North; and so we have N.E. by E., E. by N., E. by S., S.E. by E., S.E. by S., S. by E., S. by W., S.W. by S., S.W. by W., W. by S., W. by N., N.W. by W., N.W. by N., N. by W.; in this manner we get other sixteen points. We have thus got names to all the thirty-two points of the compass.

Each point is again sub-divided into half points and quarter points.

A *half point,* which is the middle division between two points, is called after that one of its adjacent points which is either a cardinal point or is the nearest to a cardinal point. Thus, the middle division between N. and N. by E. is called North-*half*-east (written N. ½ E.) Half points near N.E., N.W., S.E., and S.W., take their name from these points. Thus we say N.E. ½ N., N.E. by E. ½ E.†

The same holds for a quarter and for three-quarters as for a half point, all of which are named upon the same principle as the subordinate points.

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* These new directions also give names to the four quarters of the compass, as, when we say that "the wind is in the S.W. quarter," meaning thereby not exactly S.W., but somewhere between S. and W.

† In naming the half and quarter points it is advisable in some cases to sacrifice system to simplicity. Thus, for example, seamen commonly say N.N.E. ½ E. instead of N.E. by N. ½ N.; we do not, however, say E.N.E. ½ E., though this is simpler than E. by N. ½ N., since it is at once seen to be 6½ points. It would of course be more systematic, as a matter of geometry, to reckon the half points always from N. or S., because the ship's course is reckoned from the meridian; but on the other hand, as a matter of names, regard will be had to the whole points between which it falls, and to the order in which these are taken.

In chosing the name to use we must be guided by circumstances. In some problems it is convenient always to reckon uniformly from North or South, but generally the simpler name will be the preferable one; and similarly for quarters and three-quarters of a point.

(2.) **By Degrees.**—The whole circumference is divided into three hundred and sixty degrees (360°), each degree into sixty minutes (60′). This furnishes a notation for the compass more minute than points, half points, and quarter points. We still reckon from the cardinal points: thus, to indicate a division which has 72° 48′ to the East of North we write N. 72° 48′ E.

92. The name of the opposite point to any proposed point is known at once without referring to the compass, by simply reversing the name or the letters which compose it—thus, the opposite of N. being S. and of E. being W., the opposite point of N.E. by N. is at once known to be S.W. by S., the opposite of W. ¾ S. is E. ¾ N., and so on.

93. Repeating the points in any order is called *boxing the compass;* to do this is, of course, one of the first things a seaman learns.

94. As the ship's course, which is sometimes expressed in points and sometimes in degrees, is always reckoned from the North or South point, the seaman has to refer at once, in using the Tables, to the *number of points* or *degrees* in any course given by *name*. The following table, which exhibits the degrees, minutes, and seconds in each quarter point of the compass will be convenient for reference.

A TABLE OF THE ANGLES,

which every Point and Quarter Point of the Compass makes with the Meridian.

NORTH		Points	°	′	″	Points	SOUTH	
		0 ¼	2	48	45	0 ¼		
		0 ½	5	37	30	0 ½		
		0 ¾	8	26	15	0 ¾		
N. by E.	N. by W.	1	11	15	0	1	S. by E.	S. by W.
		1 ¼	14	3	45	1 ¼		
		1 ½	16	52	30	1 ½		
		1 ¾	19	41	15	1 ¾		
N.N.E.	N.N.W.	2	22	30	0	2	S.S.E.	S.S.W.
		2 ¼	25	18	45	2 ¼		
		2 ½	28	7	30	2 ½		
		2 ¾	30	56	15	2 ¾		
N.E. by N.	N.W. by N.	3	33	45	0	3	S.E. by S.	S.W. by S.
		3 ¼	36	33	45	3 ¼		
		3 ½	39	22	30	3 ½		
		3 ¾	42	11	15	3 ¾		
N.E.	N.W.	4	45	0	0	4	S.E.	S.W.
		4 ¼	47	48	45	4 ¼		
		4 ½	50	37	30	4 ½		
		4 ¾	53	26	15	4 ¾		
N.E. by E.	N.W. by W.	5	56	15	0	5	S.E. by E.	S.W. by W.
		5 ¼	59	3	45	5 ¼		
		5 ½	61	52	30	5 ½		
		5 ¾	64	41	15	5 ¾		
E.N.E.	W.N.W.	6	67	30	0	6	E.S.E.	W.S.W.
		6 ¼	70	18	45	6 ¼		
		6 ½	73	7	30	6 ½		
		6 ¾	75	56	15	6 ¾		
E. by N.	W. by N.	7	78	45	0	7	E. by S.	W. by S.
		7 ¼	81	33	45	7 ¼		
		7 ½	84	22	30	7 ½		
		7 ¾	87	11	15	7 ¾		
East.	West.	8	90	0	0	8	East.	West.

95. The card for practical use is generally made of mica covered with paper, so as to be as light as possible. Two or more magnetic needles,* which are small steel bars magnetised, are fixed below the circular compass card, but parallel with its meridional line, so that the N. ends of the needles shall coincide (in direction) with the N. end of that line, and the S. ends of the needles with the S. end of the same line. An inverted conical brass socket, called a cap, with a hard stone in its centre, is passed through a hole in the centre of the card, and the whole is then accurately balanced on a sharp centre or pivot rising from the middle of a brass or copper bowl, and sufficiently large to admit of the card moving freely within it: the cover of the bowl is glass, which, while protecting the card from wind and weather, admits of its indications being distinctly seen. There is also a vertical line drawn inside the bowl which is called the *lubber's line.* The bowl, having a weight fixed to it below, is placed in *gimbals,* which are brass hoops or rings so arranged as to admit of motion about two horizontal axis at right-angles to one another, *i.e.*, each turning upon two pivots at opposite points of the hoop next greater in size; by this means the loaded bowl remains nearly horizontal during the confused and irregular motion of the ship.

To the deck, in front of the helmsman's position, a stand called a *Binnacle* is firmly fixed, which may be of any shape—octagonal, square, or pillar-like—sometimes of wood, sometimes of brass: within it are supports or bearings into which the pivots or outer rings of the compass bowl fit, and its moveable top or cover is fitted with a glass front and a lamp or lamps to cast a light on the compass card by night. This constitutes the *Steering Compass.*

96. The helmsman steers the ship so that a line parallel to the keel passes over the centre of the card, and the point prescribed as the course. Care is taken to place the box so that the *lubber's point* in the bowl and the centre of the card are in a line fore-and-aft, or parallel to the keel; but as the lubber's point deviates a little from its proper position when the ship is heeled over, seamen do not implicitly depend upon it, as indeed, the name implies.

97. The Azimuth Compass is a compass of superior construction, particularly adapted to observe bearings. It is mounted on a stand, and is fitted with two small frames carrying vertical wires, called *sight-vanes,* for the purpose of observing objects elevated above the horizon. In one of these vanes there is a long and very narrow slit, and in the other is an opening of the same kind, but wider, and having a wire up and down the middle of it, exactly opposite the slit.

98. In the best modern instruments, a horizontal ring is expressly provided to carry the vertical wire frame, and instead of having a wire next the eye, a glass prism, acting by internal reflection, is placed there, so arranged that one-half of the pupil of the eye can observe the wire on the further side of the horizontal ring and the distant object, and the other half of the pupil can see the graduations of the compass card by internal reflection in the prism. This prism is a solid piece of glass, whose sides are parallelograms and ends triangles. The compass card is very carefully and minutely graduated; besides the points and quarter points being marked, the circumference over which the prism passes is graduated in degrees, and usually cut to every 20′, and this graduation is arranged so that we may read off the bearing at once, and is reckoned in more ways than one, for facilitating taking bearings from different cardinal points. The card can be brought to rest by a stop. There is also a contrivance for throwing the card off its centre when the instrument is not in use, to prevent the fine pivot being worn, and the sensibility of the compass impaired. This instrument is known as the **Prismatic Azimuth Compass.**

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* The object of using several magnets is to increase the magnetic moment of a given weight of steel.

99. In observing bearings on board ship the card should never be stopped, but two or more bearings being read off as quickly as convenient, the mean should be used; for, as the vessel, and consequently the compass card, have always some motion, the card may not therefore be stopped exactly in the middle of its vibration, which, as it may be supposed to vibrate equally on both sides of the line of direction of the object, is essential to the true result.

100. The Standard Compass on board ship is the one placed in a particular spot on deck, or above it. It should be placed in the middle of the ship, and fixed on a permanent and secure pillar or support, raised at such a height (not less than 5 feet) as to permit amplitudes of the sun and bearings of the land to be conveniently observed by it. In the royal navy it is used as an azimuth compass, being fitted with an azimuth circle, which is graduated so as to show the angle between the ship's head and any heavenly body, as measured on the horizon (thus acting as a *dumb card*); the sight vanes and reading prism being fitted to the azimuth circle in such a way as to turn freely in azimuth without moving the compass or disturbing the card. The card of the azimuth compass should not exceed 7 to 7½ inches diameter.

It should also be in a position as far as possible removed from any considerable mass of iron—at least 5 feet from iron deck beams—and should not be within 10 feet of the extremity of any elongated iron mass, especially if vertical, such as funnels, stanchions, or the spindle of the wheel; and it should be received as a general rule that no iron subject to occasional removal is to be placed within 15 feet of this compass, either on the same deck, or that below it.

But in the mercantile marine the practice prevails of taking these bearings by means of a dumb card, many of which are in use and answer the purpose intended.* They can be placed in any part for observing, and the true bearing of the ship's head is determined, so that by comparing it with the bearing shown by the Standard Compass the deviation of the latter can be ascertained. Under these circumstances we recommend that the only consideration for determining the selection of a place for the Standard Compass should be favourable conditions connected with its compensation. The place chosen should be where the deviation arising only from *horizontal*, induced, and subpermanent magnetism, since deviation arising from these causes when compensated in one latitude will remain so in every other.

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* Perhaps the best and most useful of these is the one known as BAIN & ANSLEY'S "Compass Corrector."

There is a very common error prevalent respecting the best position of the ship's deck for a compass. Some of the earliest writers lay it down as an axiom that on the deck of all iron ships there is a neutral point which should be sought out for fixing the compass. That an apparently neutral line does frequently exist is admitted. But this very point is very frequently a most dangerous position for fixing a compass. It is neutral only when the ship is in the same locality.

101. Steering Compasses being placed according to the requirements of the ship, the moderate and uniform amount of deviation generally attainable at the Standard Compass by selection of position, cannot always be secured. Still we should do the best we can, for if, as frequently happens, the steering wheel is placed near an iron stern-post or rudder-head, and further fitted with an iron spindle—near which, of necessity, the steering compass is fitted—then large and perplexing deviations may be expected, defying even approximate correction by magnets, causing much inconvenience to the helmsman, and possibly a total loss of the services of the compass on the ship proceeding into southern latitudes.[*]

The following rules to avoid the inconvenience and even danger just pointed out, have been recommended in selecting a place for steering compasses:—"Not to be within half the width of the ship from the stern-post or rudder-head; the spindle of the steering wheel and the foremost support on which the wheel works *not* to be of iron; avoid vertical iron." The needle should be at least 3 ft. 6 in. from iron deck beams, and as much higher as can be made convenient to the helmsman.

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[*] **Bridge Compass.**—Those who arrange for the construction and equipment of iron steamers ought not to lose sight of the fact that the bridge compass is the most important of all. It is on the bridge where the officer of the watch is stationed on all occasions when caution is required, and if the compass before him is a reliable one he is better enabled to navigate the ship safely than by a compass situated in any other part. Yet many errors are committed in placing this compass. Take an instance, "where the bridge compass was rendered untrustworthy from the ventilator of the engine-room being *close* in front of it. Two reasons were assigned for this. The one was that the bell-mouthed top required to be turned round in order to regulate the amount of ventilation, it was convenient to have it within reach of the bridge. The other was, that in placing the bridge farther from the ventilator a greater evil would be incurred, since it would require that the compass should either be brought nearer to the iron mast or nearer to the funnel. It was not understood that this ventilator, small as it was compared with the mast or the funnel, produced five times as much error as these two combined, if placed equally near. The head of the ventilator was a blue pole by induction, and was on a level with the compass, and when the bell-mouth, or cowl, was turned towards the stern, not two feet from the compass on the bridge, it caused two points of deviation, but when the cowl was turned towards the bows only a half point of error was produced, and when turned to the starboard or port side other complications resulted rendering the compass useless, because the red pole of the ventilator was so far distant as to render no appreciable amount of repulsion to compensate the attraction of the upper pole. But the blue and red poles of the mast and funnel were situated one above the compass and the other below, so as nearly, if not altogether, to compensate each other. Thus, being ignorant of the laws which regulate deviation, in attempting to avoid an imagined evil, a serious real error was committed. This compass being found unworthy of reliance was removed, and the captain in ascending the Gulf of St. Lawrence had continually to refer to the Standard Compass on the deck, which in hazy weather rendered the navigation more difficult than it would have been had there been a trustworthy bridge compass." Again, it not unfrequently happens that the bridge on which the compass stands is placed directly over the engine and close against the central iron stanchion which supports the rail running along the bridge, while according to another arrangement the compass stands on a semicircular piece of planking projected from the bridge forward with the railing carried round it, with perhaps, as in some instances, five and in others four iron stanchions in close proximity to the compass, while in other cases where the circular space is just large enough for the binnacle there may be only three iron stanchions, but in all these cases these iron stanchions are only a very few inches from the card, and the card itself within six inches of the plane of the top of the stanchions. It cannot be a matter of surprise that no dependence can be placed on compasses so placed.

In addition to the rules already given for the guidance of seamen, the following (given by Capt. EVANS, Superintendent of the Admiralty Compass Department) are worthy the attention of the Naval Architect and those superintending the equipment of the ship:—

(1.) In all designs for the construction of iron ships, a place to be prepared for the Standard Compass, and to be shown in the plan.

(2.) The Standard Compass not to be within half the breadth of the ship from the rudder-head and stern-post or iron-cased screw well, not to be nearer an iron deck or iron deck beams than five feet.

(3.) In ships built near *North*, the Standard Compass to be as far *forward* as the requirements of the ship will permit. In ships built head near *South* to be as far aft as the requirements of the ship will permit, subject to Rule 2. In ships built nearly *East* or *West*, the Standard Compass not to be near either extremity of the vessel.

(4.) To be as far as possible from transverse iron bulkheads.

(5.) As far as possible, no masses of iron—as boilers, engines, bulkheads, or stanchions—should be placed below the compass, or within 55° of the vertical line through the centre, the angle being drawn from the compass as centre to the centre of the mass in question.*

(6.) To the above we would add, not to be nearer the break of the poop, either before or aft, than half the breadth of the vessel.

NOTE.—"**Comparative Merits of Large and Small Compasses.**—Of late years, Capt. EVANS, R.N., states in *Manual of the Deviation of the Compass*, much diversity in practice has prevailed as to the size of compasses for use on board ship. The Admiralty Standard Card, for example, is fitted with needles, the maximum lengths of which are 7½ inches, while in large passenger steam vessels the needles are frequently 12 to 15 inches and even longer. The chief object in the employment of large compasses is to enable the helmsman to steer to degrees, and a more accurate course is presumed to be preserved.

"With reference to this increased size it must be observed that competent authorities limit the length of efficient compass needles to 5 or 6 inches; beyond this limit an increase of length is alone accompanied by an increase of directive power in the same proportion, and if the thickness of the needle be preserved, the weight, and consequently the friction, increases in the same ratio. No advantage of directive power is therefore gained by increase of length, but with the increased weight of the card and appendages, the increase of friction probably far exceeds the increase of directive force; sluggishness is the result, which is further exaggerated by the extreme slowness of oscillation of long needles compared with short ones.

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* Investigation has shown that the effect of a sphere of iron within this cone is prejudicial by diminishing the directive force and increasing the heeling error to windward—when without the cone it would be beneficial in both respects. Hence the recommendation.

With reference to the magnetic character of boilers, or tanks, it has been stated that the effect is the same as if they were solid bodies, on the assumption that magnetism exists entirely on the surface of iron masses. This is not the case; it is, however, true that the effect of hollow masses of iron increases very rapidly with the increase of the thickness of the iron, so that the limit of thickness is speedily reached when the effect of the body is sensibly the same as if it were solid; for example, in a tank 4 feet in diameter and 1-10th of an inch thick, the effect is about ¼ of a solid mass of the same size; in a similar sized tank ⅛ of an inch thick, the effect would be about half that of a solid mass. See a valuable investigation by Mr. ARCHIBALD SMITH, in the Phil. Trans. for 1865, pages 304-318.

"Large cards, however convenient in practice, are therefore not without danger, for the course steered may deceive the seaman by seeming right to the fraction of a degree, but which avails little if the card itself is wrong half a point, and the ship in consequence hazarded. In the opinion of the writer, the present Admiralty Standard Card is as large as should be used for the purposes of *navigation;* and that as regards safety in the long, steady, and fast ship, the choice is really between the Admiralty Card and a smaller one. In short, the question may be thus stated: the smaller a card the more correctly it points, the larger a card the more accurately it is read."

102. There is no advantage in having a large number of compasses in a ship: since, unlike the mean results of a number of chronometers, for example, the mean results of any number of compasses need not necessarily be near the truth, as they may all be largely in error, and that error may be all in one direction. Hence the necessity of depending upon one compass alone, but that compass should be in the best position in the ship, of the best manufacture, and the constant attention of the navigator should be devoted to ascertain its errors.

ADJUSTMENTS OF THE COMPASS.

103. (1.) The direction of the magnetism of the needle or the "magnetic axis" should be in a line along *the middle of the needle itself,* otherwise the needle will not point with exactness to the magnetic North and South. To examine whether this is the case reverse the needle on the card. If after this reversion the N. and S. points of the card are also found to be reversed, the adjustment is good.

As this error obviously affects all points of the compass alike, it may be included in the total variation of the particular compass as found by observation, and therefore need not be made the subject of special examination.

(2.) *The pivot must be in the centre of the graduated circumference of the card.* If it is not, the difference of bearing of two objects will not be the same when measured on different parts of the edge. This adjustment is generally good.

(3.) *The line joining the eye-vane and the object-vane,* called the "*line of sight*" *of the Azimuth Compass, must pass directly over the pivot.* This condition is examined by noting carefully the bearing of a distant object, and then turning the compass half round so as to reverse the vane and the slit, and then repeating the observation with an object eight points from the first. The bearings taken directly should be identical with those taken by reversion. The effects of this error, if any, may be eliminated by taking the mean of the direct and reversed bearings every time the instrument is used.

(4.) *The sight vanes must be vertical,* i.e., *the eye-vane and the object-vane must* each be vertical.

This can be examined only on shore, by observing whether the wires coincide through their length with a plumb line, or any vertical edge. When this adjustment is not perfect, or when the bowl is not maintained in a strictly horizontal position, bearings are most correctly obtained when the object is low.

CORRECTING COURSES.

104. The Corrections of the Compass are those quantities which must be applied to the indications of the instrument to obtain the reading that would be given if the north point of the compass card always corresponded to the north point of the horizon. Three corrections are sometimes necessary to be applied to the **course steered by compass,** to reduce it to the **true course;** and the converse (see *Defs.*, page 75). These are called

1. The Leeway.
2. The Variation of the Compass.
3. The Deviation of the Compass.

1. LEEWAY.

105. See definition, page 75.

A ship is said to be **on the port tack** when the wind is on her port side, that is, on the left-hand side of a person looking forward; and **on the starboard tack** when the wind is on her starboard side, that is, on the right-hand side of a person looking forward.

Leeway is not an error of the compass, but an error of the course due to the direction and force of the wind and trim of the ship. When a ship is under sail and the wind is blowing on her side she is liable to be pressed by its force to *leeward* of the course she is endeavouring to steer, that is, her actual course is to *leeward* of the apparent course she is lying. The amount of leeway differs in different ships; depending on their construction, on the sails set, the velocity forward, and other circumstances. Experience and observation are required to judge what amount of leeway to allow in each case. The correction for *leeway* is necessary to deduce the **course made good** from the **course steered,** and it is one of the corrections to be applied in reducing the compass course to the true course in the Day's Work.

Since the effect of the wind is to drive the ship to the *left* of her intended course when she is on the *Starboard* tack, and to the *right* of the intended course when she is on the *Port* tack, we have the following Rules for allowing the *Leeway*.

RULE XXX.

1°. When the Ship is on the **Starboard Tack** *the leeway must be allowed to the* **left** *of the* Course steered.

2°. When the Ship is on the **Port Tack** *allow the leeway to the* **right** *of the* Course steered.

EXAMPLES.

Ex. 1. The course steered is N.W. by W., the wind N. by E., leeway 1¼ point.

The ship has the starboard tacks aboard; therefore, the leeway (1¼ points) allowed to the left of N.W. by W., gives corrected *Course* W. by N. ¾ N.

Ex. 2. Course by Compass S. by E., wind E. by S., leeway 2¾ points.

The ship is on the port tack, then 2¾ points allowed to the right of S. by E. is S. by W. ¾ W., the Course corrected for leeway.

Ex. 3. Course N.E. by N., the wind N.W. by N., the leeway 1 point.

The ship being on the *port* tack, 1 point to the *right* of N.E. by N. is N.E., the corrected *Course*.

Ex. 4. Course steered West, the wind N.W. by N., leeway 3½ points.

The ship is on the *starboard* tack, 3½ points to the *left* of West is S.W. ½ W., the compass course made good.

106. The points of the compass are frequently spoken of in calculation with reference to their position to the **right** or **left** of the **cardinal** point towards which the spectator, who is supposed placed in the centre of the compass, is looking.

Supposing the given point of the compass have *North* in it, then looking from the centre of the card over the cardinal point North, he has the quadrant from North to East on his right hand, and the quadrant from North to West on his left hand.

Hence any point between North and East is said to be to the **right** of North, and every point between North and West is said to be to the **left** of North; thus, N.N.E. is said to be "two points" to the right of North (for shortness usually written 2 pts. R. of N.), and W.N.W. "six points" left of North (written 6 pts. L. of N.)

Again, suppose the given point of the compass to have *South* in it, then the observer looking from the centre of the card and facing *South*, has the quadrant from South to East on the **left** hand, and the quadrant from South to West on the **right** hand.

Hence any point between the S. and E. is said to be to the **left** of South, and any point between S. and W. is said to be to the **right** of South; thus S.E. by S. is said to be "three points" to the **left** of S. (for shortness written 3 pts. L. of S.), and W. by S. is "seven points" **right** of S. (usually written 7 pts. R. of S.)

Adopting this notation the work in the above examples will stand thus:—

EXAMPLES.

Ex. 1.

Course steered N.W. by W. is	5 pts.	L of N
Leeway carries ship	1¼ „	L of N
Sum is corrected course	6¼ „	L of N
	or W. by N. ¾ N.	

Ex. 2.

Course steered S. by E. is	1 pt.	L of S
Leeway carries ship	2¾ „	R of S
The difference is	1¾ „	R of S
	S. by W. ¾ W.	

Ex. 3.

Course steered N.E. by N. is	3 pts.	R of N
Leeway carries ship	1 „	R of N
Sum is corrected course	4 „	R of N
	or N.E.	

Ex. 4.

Course steered West is	8 pts.	R of S
Leeway carries ship	3½ „	L of S
The diff. is corrected course	4½ „	R of S
	or S.W. ½ W.	

EXAMPLES FOR PRACTICE.

Correct the following courses for leeway.

	Course Steered.	Wind.	Leeway.		Course Steered.	Wind.	Leeway.
1.	S.S.W.	S.E.	1½	5.	E. ¾ N.	N. by E.	1¾
2.	S.W. ½ W.	W.N.W.	2¼	6.	N.W. ¾ N.	N.E. by E.	1¼
3.	N. by E.	E. by N.	¾	7.	S.W. by W.	S. by E.	2¼
4.	N.N.E. ½ E.	N.W. ½ N.	2	8.	N.E. ¼ E.	N. by W.	1½

(a) *When the ship is* hove-to, *take the* middle point *between that to which she* comes up *and that to which she* falls off *for the* compass course, *and correct this for leeway.*

EXAMPLES.

Ex. 1. A ship lying-to under her mainsail, with her starboard tacks aboard, comes up E. by S., and falls off to N.E. by E., making 5 points leeway. What compass course does she make good?

The middle point between E. by S. and N.E. by E. is E. by N., then 5 points to the *left* hand gives N.N.E., the compass course made good.

Ex. 2. A ship lying-to under a close-reefed main topsail, with her port (larboard) tacks on board, comes up to S.S.W. and falls off to S.W. by W., making 2½ points leeway. What compass course does she make?

The middle point between S.S.W. and S.W. by W. is S.W. ½ S., then 2½ points to the *right* hand is W.S.W.

Ex. 3. A ship lying-to comes up S. by E. and falls off to S.E. by E., the wind being S.W., making 5 points leeway: required the compass course.

The middle point between S. by E. and S.E. by E. is S.E. by S., then 5 points to the *left* hand (the ship having starboard tacks on board) is East, the compass course made good.

Ex. 4. A ship lying-to with port tacks on board, comes up W. by S. and falls off N.W. by W., making 5 points leeway. What course does she make good?

The middle point between W. by S. and N.W. by W. is W. by N., then 5 points to the *right* hand is N.N.W., the compass course made good.

2. THE VARIATION OF THE COMPASS.

107. The needle points to the magnetic North, which in few parts of the world agrees with the true North; the difference between them is called the *Variation of the Compass.*[*]

The variation is said to be *easterly* when the North end of the needle is drawn to the eastward, and *westerly* when drawn to the westward of the true North; thus when the North end of the needle points to that part of the horizon which is true N.N.W. ½ W., the variation is said to be 2½ points West; but when it points to the N. by E. part of the horizon, the *variation* is said to be 1 point East.

108. The variation is different in different places,[†] and it is also subject to a slow change in the same place, and becomes alternately East and

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[*] This is the term commonly employed by nautical men; but among men of science the term "Magnetic Declination" is usually substituted for "Magnetic Variation."

[†] At Greenwich, at the present time, the variation is 20° W., or the North end of the magnetic needle does not point exactly North, but 20° W. of North. In the West Indies the variation is 0; at Cape Farewell, 53° W.; at Cape Horn, 23° E.; at Hobart Town, 10° E.; at Canton, 1° E.; and Cape of Good Hope, 29½° W. Generally in Europe, Africa, and the Atlantic, the variation is westerly, while in America and the Pacific it is easterly.

West.[*] It also changes slightly at different times of the day.[†] Its value for each locality is indicated on charts, and always to be found by easy methods.

109. Variation is one of the **"corrections"** in deducing the **true course and bearing** from the **course and bearing observed with the compass.** It is given on the charts used in navigation.

The method of correcting Compass Courses or Bearings for Variation will be readily understood by means of an example.

Suppose the variation of the compass is found to be two points East—that is, the needle is directed two points to the right of the North point of the heavens—that is, points N.N.E. instead of N.; then the N.N.W. point of the compass card will evidently point to the true north, and every other point on the card will be shifted round two points. If, therefore, a ship is sailing *by compass* N.N.W., or, as it is usually expressed, her compass course is N.N.W., her true course will be North; that is, *two points to the right of the compass course.* In a similar manner it may be shown that when the variation is two points westerly, the true course will be *two points to the left of the compass course.*

110. To find the **true course,** the **compass course** being given.

RULE XXXI.

Allow easterly *variation to the* right *of the* compass course.
westerly ,, left ,,
looking from the centre of the card over the point to be corrected.

The learner must be careful to remember when correcting his courses that he is to suppose himself *looking from the centre of the card over the point to be corrected.* When he places the compass card before him, mistakes very frequently occur in the application of the variation between the *East* and *West* points round by *South;* thus, taking the compass, as shown in Fig. 25, with the North point placed before or from the observer, while an error could scarcely arise when correcting courses in the N.E. and N.W. quadrants, it would be different with the S.E. and S.W. quadrants, unless he bore in mind that in the latter instance the compass card should be placed before him, as if he were facing the South, *i.e.*, as in Fig. 26.

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[*] "The system of Magnetic Meridians has undergone considerable changes in the times of modern accurate science. The southern point of Africa received from the Portugese voyagers in the fifteenth century the name of L'Agulhas (the needle), because the direction of the compass needle, or the Local Magnetic Meridian, coincided with the Geographical Meridian: it now makes with it an angle of about 30° W. In the sixteenth century the compass needle in Britain pointed East of North; it now points from 20° to 30° (in different parts of the British Isles) West of North. At the present time a change of the opposite character is going on: in 1819 the westerly declination at Greenwich was about 24° 23′, which was probably its maximum; in the last 30 years it has diminished from 23½° to 20° nearly. It is believed that the magnetic poles are rotating round the geographical poles from East to West."—*A Treatise on Magnetism,* designed for the use of Students in the University. By GEORGE BIDDELL AIRY, M.A., LL.D., D.C.L.

[†] Besides the gradual changes which occur in terrestrial magnetism, both as regards direction and intensity of force, in the course of long periods of time, there are minute fluctuations continually traceable. To a certain extent these are dependent on the varying positions of the sun, and, to a much smaller extent, of the moon, with respect to the place of observation; but over and above all regular and periodic changes, there is a large amount of irregular fluctuations, which occasionally become so great as to constitute what is called a *magnetic storm.* These variations occur with great rapidity, causing deflections to the right and left comparable in their rate or period of alternation with ordinary telegraphic signalling; accidental variations of 70′ have been observed. "Magnetic Storms" are not connected with thunderstorms, or any other known disturbance of the atmosphere, but are invariably connected with exhibitions of aurora borealis, and with spontaneous galvanic currents in the telegraph wires, and this connection is found to be so certain, that upon remarking the display of one of the three classes of phenomena, we can at once assert that the other two are observable (the aurora borealis sometimes not visible here, but certainly visible in a more northern latitude).

Fig. 25.

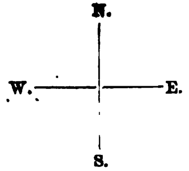
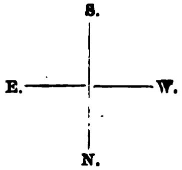


Fig. 26.



From what has been said it will be seen that in correcting courses, the significance of RIGHT on the face of a compass card, is *as the hands of a watch move over the dial*, and LEFT *the contrary direction.*

EXAMPLES.

Taking the courses between North and South round by E.

Ex. 1. Course steered N.E. by E., variation 2¾ points *West*, to find the true course.

Here the compass course is N. 5 points E., and the variation is westerly, and hence must be applied to the *left*, thereby bringing it 2¾ points nearer to the North (N. 5 E. — 2¾ = N. 2¼ E.), that is, within 2¼ points of North; the true course is therefore N.N.E. ¼ E.

Ex. 2. Course steered the same, viz., N.E. by E., variation 1¾ points East.

Here the compass course is N. 5 points E., and the variation easterly, and hence must be applied to the *right*, thereby carrying the course *away from the North towards the East*, that is, 6¾ points to the eastward of North (N. 5 E. + 1¾ E. = N. 6¾ E.); the true course is therefore E. by N. ¼ N.

Ex. 3. Course by compass N.N.E., variation 2½ points *West*, the *true course* 2½ points to the left hand of N.N.E., or N. ½ W.

Ex. 4. Compass course S. by E., variation 2½ *East*, 2½ points allowed to right of S. by E. is S. by W. ½ W., or S. 1½ W.

Ex. 5. Compass course S.E., variation 1¾ points *East*, then the *true course* (allowing the variation to the *right*) will be S.S.E. ¼ E., or S. 2¼ points E.

Ex. 6. But compass course S.E., variation 2½ points *West*, then the true course (allowing the variation to the *left*) will be E. by S. ½ S., or S. 6½ points E.

Ex. 7. Compass course East, variation 2 points *West*, then allowing 2 points to the left gives *true course* E.N.E.

Ex. 8. Compass course E., variation 2¾ points *East*, then the *true course* (allowing the variation to the right hand) is S.E. by E. ¼ E.

Now proceeding to the courses between North and South round by West.

Ex. 9. Course by compass N.W. ½ W., variation 2 points *West*, then the *true course* (allowing the variation to the *left*) will be W. by N. ½ N., or N. 6½ points W.

Ex. 10. Taking the same compass course, viz., N.W. ½ W., when the variation is 1½ points *East*, the *true course* (allowing the variation to the *right*) will be N.W. by N., or N. 3 points W.

Ex. 11. Again, compass course S.W. by S., variation 2½ points *West*, the *true course* (allowing variation to the *left*) will be S. ½ W.

Ex. 12. Compass course S.W. by S. (as before (variation 1¾ *East*, the *true course* (allowing the variation to the *right*) will be S.W. ¾ W., or S. 4¾ points W.

Ex. 13. Compass course S.S.W., variation 3½ *West*, then allowing 3½ W. to the left of S.S.W. gives S. by E. ½ E., or S. 1½ points E.

Ex. 14. Compass course W., variation 2½ E., then the *true course* (allowing 2½ points to the *right*) is N.W. by W. ½ W., or N. 5½ points W.

Ex. 15. But with compass course West, and variation 3¾ *West*, then allowing 3¾ points to the left of W., the *true course* is S.W. ¼ W., or S. 4¼ points W.

Ex. 16. Compass course N.N.W. ½ W., variation 3¼ points *East*, then 3¼ points to the right of N.N.W. ½ W., is N. ¾ E.

111. The learner should so familiarise himself with the compass card as to be able entirely to dispense with its use in correcting courses, and when he has acquired such knowledge, he will find the following rule serviceable, in which the points of the compass are treated numerically.

RULE XXXII.

1°. *Put down the* points *and* quarter points *which the* compass course *is to the* right *or* left *of* North *or* South, *marking them* R. *or* L. *accordingly.*

2°. *Underneath put the* variation, *marking it also* R. *or* L., *accordingly as it is* E. *or* W.

3°. *If the names are* **alike,** *take the* sum, *with* that name, *for the true course.*

(a) *When the* sum amounts *to* 8 points, *it is either* E. *or* W.

(b) *When the* sum exceeds 8 points, *take it from* 16 points; *the* remainder *is the true course to be reckoned from the* **opposite** point to that which the compass course is reckoned from.

That is, it is to be reckoned from the North if it had previously been reckoned from S., but marked S. if previously marked N.; also, if marked L. (left) change to R. (right); but if marked R. change to L.

4°. *If the names are* unlike, *take the* difference, *and mark it the* same name *as the* greater.

(c) *If the variation, being* subtractive, exceeds *the amount from which it is to be subtracted, take the points of the* course from *the* variation, *and name it (the course)* Right *if it had previously been* Left, *but towards the* Left *if it had been* Right.

(d) *Also bear in mind that* 0 points *is either* North *or* South, *as the case may be.*

The following are examples of this method of applying the variation, and the numbers and letters in brackets refer to the rule as given above:—

1.—Compass Courses:—S.S.W.; N. by E. ½ E.; W.S.W.; and E. by N. Variation 3½ points Easterly. Required the True Courses.

	S.S.W.	N. by E. ½ E.	W.S.W.	E. by N.
S.S.W. =	2 R. of S.	1½ R. of N.	6 R. of S.	7 R. of N.
Var.	3½ R. [3°]	3½ R. [3°]	3½ R. [b]	3½ R. [b]
Sum	5½ R. of S.	5	— 9½ R. of S.	— 10½ R. of N.
	S.W. by W. ½ W.	N.E. by E.	16	16
	Here the *sum* is taken for the *true* course, the names being alike. (See No. 3°)	Here the names being alike the *sum* is taken. (See No. 3°.)	6½ L. of N.	5½ L. of S.
			W. by N. ½ N. (See No. 3° (b).	S.E. by E. ½ E.

2. Compass Courses:—N.N.W.; S. by E.; W. ½ N.; and E. by S. Variation 2½ W.

N.N.W.	S. by E.	W. ½ N.	E. by S.
2 L. of N.	1 L. of S.	7½ L. of N.	7 L. of S.
2½ L. [3°]	2½ L. [3°]	2½ L. [b]	2½ L. [b]
4½ L. of N.	3½ L. of S.	— 10 L. of N.	— 9½ L. of S.
N.W. ½ W.	S.E. ½ S.	16	16
		6 R. of S.	6½ R. of N.
		W.S.W.	E. by N. ½ N.

3. Compass Courses:—N.E. ¾ E.; S.W. ¾ W.; N. by E.; and S. by W. Variation 2¼ points West.

N.E. ¾ E.	S.W. ¾ W.	N. by E.	S. by W.
4¾ R. of N.	4¾ R. of S.	1 R. of N.	1 R. of S.
2¼ L. [4°]	2¼ L. [4°]	2¼ L. [c]	2¼ L. [c]
—	—	—	—
2½ R. of N.	2½ R. of S.	1¼ L. of N.	1¼ L. of S.
—	—	—	—
N.N.E. ½ E.	S.S.W. ½ W.	N. by W. ¼ W.	S. by E. ¼ E.

4. Compass Courses:—N.W. by W.; S.E. by E.; N. by W. ½ W.; and S. by E. Variation 3¼ points East.

N.W. by W.	S.E. by E.	N. by W. ½ W.	S. by E.
5 L. of N.	5 L. of S.	1½ L. of N.	1 L. of S.
3¼ R. [4°]	3¼ R. [4°]	3¼ R. [c]	3¼ R. [c]
—	—	—	—
1¾ L. of N.	1¾ L. of S.	1¾ R. of N.	2¼ R. of S.
—	—	—	—
N. by W. ¾ W.	S. by E. ¾ E.	N. by E. ¾ E.	S.S.W. ¼ W.

5. N.N.E., Variation 2 points W.; S. by E., Variation 1 point E.; W. by S., Variation 1 point E.; and E.S.E., Variation 2 points W.

N.N.E., Var. 2 W.	S. by E., Var. 1 E.	W. by S., Var. 1 E.	E.S.E., Var. 2 W.
2 R. of N.	1 L. of S.	7 R. of S.	6 L. of S.
2 L.	1 R.	1 R.	2 L.
—	—	—	—
0 [d]	0 [d]	8 R. of S. [a]	8 L. of S. [a]
—	—	—	—
N.	S.	W.	E.

6. North, Variation 2 points E.; South, Variation 2 points W.; West, Variation 2 points W.; and East, Variation 2 points E.

N., Var. 2 E.	S., Var. 2 W.	W., Var. 2 W.	E., Var. 2 E.
0 = N.	0 = S.	8 R. of S.	8 L. of S.
2 R. of N.	2 L. of S.	2 L.	2 R.
—	—	—	—
2 R. of N. [3°]	2 L. of S. [3°]	6 R. of S. [4°]	6 L. of S. [4°]
—	—	—	—
N.N.E.	S.S.E.	W.S.W.	E.S.E.

112. If the variation be given in degrees proceed as follows:—

RULE XXXIII.

1°. *Express the* course *in* degrees, *marking them* R. *or* L. *according as they are* right *or* left *of* N. *or* S.

2°. *Underneath write the variation, marking it* R. *or* L. *according as it is* E. *or* W.

3°. *If the* names *are* **alike,** *take the* sum, *with* that name, *for the true course.*

(a) *When the* sum amounts to 90° *it is either* E. *or* W.

(b) *When the* sum exceeds 90° *take it from* 180°, *the* remainder *is the true course, to be* reckoned *from the* **opposite point** to that which the compass course is reckoned from; *also* change *the* letter R. or L.

Note.—That is, it is to be reckoned from the North if it had previously been reckoned from South, but marked S. if previously marked N.; also, if marked L. (left) change to R. (right), but if marked R. change to L.

4°. *If the* names *are* **unlike,** *take the* difference *and mark it the* same name *as the* greater.

(c) *If the variation, being* subtractive, **exceeds** *the amount* from which *it is to be* subtracted, *take the* degrees *of the* course *from the* variation, *and name the* remainder R. *or* L., *according as the* variation *is* marked R. *or* L.

(d) *Also remember* that 0° *is either* North *or* South, *as the case may be.*

1. Compass Courses:—N.N.E.; S. by W. ½ W.; W.N.W.; S.E. ½ E. Var. 36½° E.

N.N.E. (1).	S. by W. ½ W. (1).	W.N.W. (2).	S.E. ½ E. (2).
22°30′ R. of N.	16°53′ R. of S.	67°30′ L. of N.	50°38′ L. of S.
36 30 R.	36 30 R.	36 30 R.	36 30 R.
59 0 R. of N.	53 23 R. of S.	31 0 L. of N.	14 8 L. of S.
N. 59° E.	S. 53° W.	N. 31° W.	S. 14° E.

2. Compass Course:—E.N.E.; W. by S.; N.N.W.; S. by E. Var. 36° 30′ E.

E.N.E. (b)	W. by S.	N.N.W.	S. by E.
67°30′ R. of N.	78°45′ R. of S.	22°30′ L. of N.	11°15′ L. of S.
36 30 R.	36 30 R.	36 30 R.	36 30 R.
104 0 R. of N.	115 15 R. of S.	14 0 R. of N.	25 15 R. of S.
180	180	N. 14° E.	S. 25° W.
76 0 L. of S.	64 45 L. of N.		
S. 76° E.	N. 65° W.		

3. Compass Courses:—N.E.; S.W. ½ S.; N.W. ½ N.; S.E. ¼ S. Var. 25° 19′ W.

N.E. (4)	S.W. ½ S. (4)	N.W. ½ N. (3)	S.E. ¼ S. (3)
45° 0′ R. of N.	39°23′ R. of S.	39°23′ L. of N.	42°11′ L. of S.
25 19 L.	25 19 L.	25 19 L.	25 19 L.
19 41 R. of N.	14 4 R. of S.	64 42 L. of N.	67 30 L. of S.
N. 20° E.	S. 14° W.	N. 65° W.	S. 67½ E.

4. Compass Courses:—N. by E.; S. by W. ¼ W.; W. ½ N.; E. by S. Var. 25° 19′ W.

N. by E. (4)	S. by W. ¼ W. (4)	W. ½ N. (b)	E. by S. (b)
11°15′ R. of N.	14° 4 R. of S.	84°23′ L. of N.	78°45′ L. of S.
25 19 L.	25 19 L.	25 19 L.	25 19 L.
14 4 L. of N.	11 15 L. of S.	109 42 L. of N.	104 4 L. of S.
N. 14° W.	S. 11° E.	180	180
		70 18 R. of S.	75 56 R. of N.
		S. 70° W.	N. 76° E.

5. Compass Courses:—N.N.E., Var. 22° 30′ W.; S. by E., Var. 11° 15′ E.; W. by S., Var. 11° 15′ E.; and E.S.E., Var. 22° 30′ W.

N.N.E.	S. by E.	W. by S.	E.S.E.
22°30′ R. of N.	11°15′ L. of S.	78°45′ R. of S.	67°30′ L. of S.
22 30 L.	11 15 R.	11 15 R.	22 30 L.
0 0 [d]	0 0 [d]	90 0 R. of S. [a]	90 0 [a]
North.	South.	West.	East.

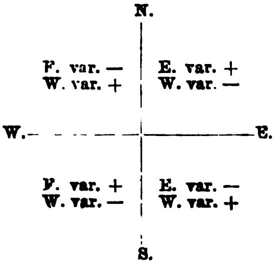
113. If the learner has carefully gone through the preceding examples, he will have noticed that *Easterly* variation in its application to Compass Courses *increases* them in the *N.E.* and *S.W.* quarters of the compass, and *decreases* them in the *N.W.* and *S.E.* quarters. *Westerly* variation *decreases* the courses in the *N.E.* and *S.W.* quadrants, and *increases* it in the *N.W.* and *S.E.;* we have, therefore,

RULE XXXIV.

1. Westerly variation is — from all points between N. and E. ....S. and W.
2. Easterly variation is + to all points between N. and E. ....S. and W.
3. Westerly variation is + to all points between N. and W.....S. and E.
4. Easterly variation is — from all points between N. and W.....S. and E.

Which may be represented by means of a simple diagram.

Fig. 27.



(a) *Also, when the* Variation *is* additive (+) *to the* course, *if the* sum **exceed** 90°, subtract *it* from 180°, *and reckon the* remainder *from* N. *if it had previously been* S., *but from* S. *if it had previously been* N.

(b) *When the* Variation *is* subtractive (—), *and* **exceeds** *the* quantity *from which it is to be* taken, subtract *the* degrees *of the* Course *from the* Variation, *and* name *the* remainder toward the W. *if the* Course *had previously been* E., *but towards the* E. *if it had been* W.

(c) *Also,* remember *that* 0° *is either* N. *or* S., *as the case may be.*

(d) *And* 90° *is either* E. *or* W.

The following examples of this method of applying the variation, and the Nos. and letters in brackets refer to the rule just given.

1. Compass Courses:—N.N.E.; S. by W. ½ W.; W.N.W.; S.E. ½ E. Var. 36° 34′ E.

N.N.E. (1)	S. by W. ½ W. (1)	W.N.W. (2)	S.E. ½ E. (2)
N. 22°30′ E.	S. 16°53′ W.	N. 67°30′ W.	S. 50°38′ E.
+ 36 34 E.	+ 36 34 E.	— 36 34 E.	— 36 34 E.
N. 59 4 E.	S. 53 27 W.	N. 30 56 W.	S. 14 4 E.

2. Compass Courses:—E.N.E.; W. by S.; N.N.W.; S. by E. Var. 36° 34′ E.

E.N.E. (a)	W. by S. (a)	N.N.W. (b)	S. by E. (b)
N. 67°30′ E.	S. 78°45′ W.	N. 22°30′ W.	S. 11°15′ E.
+ 36 34 E.	+ 36 34 E.	— 36 34 E.	— 36 34 E.
N. 104 4 E.	S. 115 19 W.	N. 14 4 E.	S. 25 19 W.
180	180		
S. 75 56 E.	N. 64 41 W.		

3. Compass Courses:—N.E.; S.W. ½ S.; N.W. ½ N.; S.E. ¼ S. Var. 25° 19′ W.

N.E. (1)	S.W. ½ S. (1)	N.W. ½ N. (3)	S.E. ¼ S. (3)
N. 45° 0′ E.	S. 39°23′ W.	N. 39°23′ W.	S. 42°11′ E.
— 25 19 W.	— 25 19 W.	+ 25 19 W.	+ 25 19 W.
N. 19 41 E.	S. 14 4 W.	N. 64 42 W.	S. 67 30 E.

4. Compass Courses:—N. by E.; S. by W. ¼ W.; W. ½ N.; E. by S. Var. 25° 19′ W.

N. by E. (b)	S. by W. ¼ W. (b)	W. ½ N. (a)	E. by S. (a)
N. 11° 15′ E.	S. 14° 4′ W.	N. 84° 23′ W.	S. 78° 45′ E.
— 25 19 W.	— 25 19 W.	+ 25 19 W.	+ 25 19 W.
N. 14 4 W.	S. 11 15 E.	N. 109 42 W.	S. 104 4 E.
		180	180
		S. 70 18 W.	N. 75 56 E.

5. Compass Courses:—N.N.W. ¾ W.; S.S.E. ¾ E.; N.E. by E. ¼ E.; S.W. by W. ¼ W. Var. 30° 56′ E.

N.N.W. ¾ W. (c)	S.S.E. ¾ E. (c)	N.E. by E. ¼ E. (d)	S.W. by W. ¼ W. (d)
N. 30° 56′ W.	S. 30° 56′ E.	N. 59° 4′ E.	S. 59° 4′ W.
30 56 E.	30 56 E.	30 56 E.	30 56 E.
0 0	0 0	N. 90 0 E.	90 0
or, North.	South.	East.	West.

114. Sometimes it may be desirable to express the Variation in degrees, in which case we proceed as follows:—

RULE XXXV.

1°. *Correct the compass courses for leeway as before directed, and convert the number of points thus found into degrees, marking them* R. *or* L., *according as they are* right *or* left *of* N. *or* S.

2°. *Underneath write the variation, marking it* R. *or* L., *according as it is* E. *or* W. *Take the* sum *with the common name, if the names are* alike, *and the* difference *with the name of the* greater, *if the names are* unlike. The result will be the number of degrees the *true course* is from N. or S. *according as the course, corrected for leeway, is reckoned from the* N. *or* S.

(a) *If in taking the sum the number of degrees* exceed 90° *take the* supplement to 180°, *and reckon the* true course *from the* opposite *point to that* from *which the* course *corrected for* leeway *is reckoned; also change the letter* R. *or* L.

(b) When the sum amounts to 90° it is either East or West.

Examples.

Compass Course.	Winds.	Leeway.	Var.	True Course.
S.W. ½ S.	W. by N. ½ N.	¾	23° W.	S. 8° W.
N. by E.	E. by N.	3¼	20° E.	N. 5° W.
W. ¾ N.	S.W. by S.	1	25° W.	S. 85° W.

	S.W. ½ S. = 3½ R. of S.	N. by E. = 1 pt. R. of N.	W. ¾ N. = 7¼ L. of N.
	3½ R. of S.	1 R. of N.	7¼ L. of N.
Leeway	¾ L.	3¼ L.	1 R.
	2¾ R.	2¼ L.	6¼
	or 31° R. of S.	or 25° L. of N.	or 70° L.
Var.	23 L.	20	25 L.
	8 R. of S.	5 L. of N.	— 95 L. of N.
			180
			85 R. of S.
	S. 8° W.	N. 5° W.	S. 85° W.

115. Deviation is also one of the **corrections** in deducing the **true course** and **bearing** from the **course** and **bearing** observed with the **compass.**

The compass course corrected for deviation gives the correct magnetic course, and it is usual to correct the compass course first for deviation and then for variation.

The deviation of the compass being Easterly or Westerly, as in the case of the variation (but it differs on each point), the rule for applying it to a compass course steered is also similar; hence,

RULE XXXVI.

116. *To find the* **correct magnetic course,** having given the **compass course** and **deviation.**

Express the compass course in degrees, &c, and apply the Deviation *for the given course,*

Allowing Easterly deviation to the right.
Westerly ,, left.

looking from the centre of the card over the point to be corrected.

Examples.

Correct the following compass courses for the given deviation.

1. Compass Course E.S.E., Dev. 9° 8′ E.

E.S.E. = 6 points L. of S.
6 points L. of S. = 67° 30′ L. of S.
Deviation (Table) 9 8 R.
Cor. *mag. course* 58 22 L. of S.
or S. 58 22 E.

In this instance, the deviation being Easterly, allow to the right.

Ex. 3. Compass Course E. ½ N., Deviation 14° E.

E. ½ N. = 7½ points R. of N.
7½ points R. of N. = 84° 23′ R. of N.
Deviation 14 0 R.
Exceeds 90° 98 23 R. of N.
Subtract from 180
Corr. mag. course 81 37 L. of S.
or S. 82° E.

2. Compass Course N.N.W., Dev. 5° 2′ W.

N.N.W. = 2 points L. of N.
2 points L. of N. = 22° 30′ L. of N.
Deviation (Table) 5 2 L.
Cor. *mag. course* 27 32 L. of N.
or N. 27 32 W.

The deviation in this instance being Westerly, allow to the left.

Ex. 4. Compass Course S. by W., Deviation 25° W.

S. by W. = 1 point R. of S.
1 point R. of S. = 11° 15′ R. of S.
Deviation 25 0 L.
Corr. mag. course 13 45 L. of S.
or S. 14° E.

Examples for Practice.

	Compass Courses.	Deviation.		Compass Courses.	Deviation.
1.	S. ½ E.	15° 40′ E.	5.	S. by W. ¼ W.	20° W.
2.	N. ¼ W.	12 30 E.	6.	N. by W.	50 E.
3.	W. ½ S.	25 0 W.	7.	S.S.E.	25 W.
4.	S. ¾ E.	31 0 E.	8.	W. by N. ½ N.	19½ W.

Having learnt how to apply leeway, variation, and deviation, as separate quantities, we now proceed to find their joint effect on the compass course, and thence determine the true course; in doing which, if the leeway and **variation are given in points,** it will **shorten the work to** ***take the*** **sum** ***of the*** *two when they are in the* same *direction, or their* difference *when they are in* opposite *directions; apply this* sum *or* difference (as the case may be) *to the* compass course, *then to this* result, *turned into degrees, &c., apply the deviation.*

Again, if the variation and deviation are both expressed in degrees, it will be convenient to proceed as follows:—

If they are both *of the same name,* i.e., both E. *or* both W., add *one to the other and apply the* sum *according to their joint name.*

Ex. 1. Compass Course N.N.E.: given the deviation 8° 10′ E. and the variation 20° 10′ E., the *sum* thereof 28° 20′ E. being applied to the right of N.N.E. (= N. 22° 30′ E.) gives N. 50° 50′ E.

But if one be E. *and the other* W. *take their* difference, *give it the* name *of the* greater, *and apply it according to that name.*

Ex. 2. Suppose the deviation be still 8° 10′ E., but with the variation 20° 10′ W., their difference 12° 0′ W. applied to the *left* hand will give N. 10° 30′ E. for the true course.

117. The following examples are designed to show the method of correcting courses for leeway, variation, and deviation.

Examples.

Ex. 1. Course steered E.N.E.; wind S.E.; leeway 2½ points; variation 17° E.; deviation 21° E.: required the true course.

Here the course by compass is E.N.E., or..........	6 points right of North.
The ship being on the starboard tack the leeway is applied to the left, and hence	2½ „ left.
The difference is the course corrected for leeway ..	3½ „ right of North.
Which expressed in degrees, &c., is	39° 22′ right of North.
The deviation and variation are of *same* name, their sum, viz., (17° E. + 21° E.) 38° E. is..........	38 0 right.
True course	77 22 right of North.
	Or N. 77° 22′ E.

In this example the compass course and leeway are expressed in points, we therefore take the course and allow the leeway from the wind, giving the course corrected for leeway, viz., 3½ points *right* of North, which, expressed in degrees, is 39° 22′ right of North; then since the variation and deviation are both of the *same* name add one to the other, and apply the sum according to their joint names, *i.e.*, to the right, both being E.: the result is the true course required.

Ex. 2. Course by compass N.N.W.; wind N.E.; leeway 2½ points; variation 45° W.; deviation 16° 52′ E.: find the true course.

Here the ship's course is N.N.W.	2 points left of North.
The ship being on the starboard tack the leeway is applied to the left, and hence is	2½ „ left.
Therefore the sum is the course corrected for leeway	4½ „ left.
Which expressed in degrees, &c., is	50° 38′ left of North.
The variation and deviation are of *contrary* names, their difference, viz., (45° W. — 16° 52′ E.) 28° 8′ W. is	28 8 left.
Sum	78 46 left of North.

True course N. 78° 46′ W., or W. by N.

In this example the compass course and leeway are given in points, we therefore take the course and allow the leeway from the wind, which gives the course corrected for leeway, viz., 4½ points left of North, which expressed in degrees, &c., is 50° 38′ L. of N.; then the difference of the variation and deviation is taken, as they are of *contrary* names, the remainder —which takes the name of the *greater* (W.)—is then applied; the result is the true course.

Ex. 3. Course by compass W. by S.; wind S. by W.; leeway 1¾ points; variation 36° 34′ E.; deviation 13° 50′ W.: find the true course.

Compass course W. by S. or	7 points	right of South.
Leeway, port tack allowed to the right...........	1¾ „	right.
Sum exceeds 8 points............................	8¾ „	right of South.
Subtract from	16	
	7¼ „	left of North.
	or 81°34′	left of North.
Variation and deviation are of contrary names, the difference, viz., (36° 34′ E. — 13° 50′ W.) = 22° 44′ E.	22 44	right.
True course	58 50	left of North.
	or N. 58°50′ W.	

Examples for Practice.

From the following Compass Courses find the True Courses:—

1.	South	W.S.W.	2¾ pts.	16° 52′ E.	14° 4′ E.
2.	E. ¾ S.	S. by E.	1¾ „	42 0 E.	15 0 E.
3.	W.N.W.	North	3 „	42 0 E.	18 30 W.
4.	N.E. by E.	N. by W.	½ „	14 0 E.	19 0 E.
5.	W. by S.	S. by W.	¼ „	10 30 E.	19 0 W.
6.	South	E.S.E.	¾ „	17 0 W.	3 0 E.
7.	West	N.N.W.	1¼ „	18 30 E.	21 0 W.
8.	S.S.W. ¼ W.	S.E. by S.	2½ „	17 0 W.	5 0 W.
9.	N.W. by W.	N. by E.	3 „	25 0 W.	7½ W.
10.	E. by N.	S.E. by S.	1¾ „	32 0 E.	12 0 E.
11.	W. by S. ½ S.	S. by W.	2 „	15 0 E.	15 0 W.
12.	E. ½ S.	N.N.E. ½ E.	2½ „	21 0 W.	4 0 W.
13.	S.W. by S.	W. by N.	1½ „	25 0 E.	10 0 W.
14.	South	E.S.E.	1¼ „	52 0 W.	2 0 E.
15.	S.W. ½ S.	S.S.E. ½ E.	1½ „	52 0 W.	13 0 W.
16.	E. ½ S.	S. by E. ½ E.	¾ „	52 0 W.	24 0 E.
17.	East	S.S.E.	2¼ „	8 30 E.	15 35 E.
18.	W. ¼ N.	N.N.W.	1¾ „	8 30 E.	21 30 W.
19.	N. ½ W.	W. by N.	½ „	15 45 E.	6 0 W.
20.	E. ¼ N.	N.N.E.	2¼ „	13 0 W.	20 0 E.
21.	N. by W. ½ W.	N.E. ½ E.	2½ „	53 0 W.	8½ W.
22.	N.N.E.	East	1¼ „	25 0 W.	6 0 E.
23.	S. ½ W.	W. by S. ½ S.	1¼ „	25 0 W.	14 0 E.
24.	W.N.W.	S.W.	1 „	25 0 W.	9 0 W.
25.	S.W.	W.N.W.	1¼ „	25 0 W.	6 0 W.
26.	E. ¾ N.	N. by E.	3¼ „	42 0 E.	19¾ E.
27.	West	S.S.W.	1 „	70 0 W.	16 0 W.
28.	S.W. by S.	S.E. by S.	3¼ „	70 0 W.	5 0 W.
29.	S. by E.	S.W. by W.	2¼ „	70 0 W.	4 0 E.
30.	S. ½ W.	W. by S.	2¼ „	59 0 W.	50 0 W.
31.	E. ¾ N.	N. by E.	3¼ „	59 0 W.	16½ W.
32.	E. by S. ¾ S.	N.E.	3 „	37 0 E.	14 0 E.
33.	S.W. ¾ W.	S. by E.	3½ „	59 0 W.	9 0 W.
34.	N.E. ¼ N.	N.N.W.	¼ „	37 0 E.	8 0 E.

RULE XXXVII.

118. *To find the compass course,* the true course and variation being given.

Easterly variation is allowed to the left.
Westerly „ „ right.

Examples.

Taking the courses between *North* and *South* round by *East.*

Ex. 1. Let the true course be N.E. by E., where the variation is 1¼ points *West*, the *compass* course (allowing westerly variation to the *right*) will be E.N.E. ¼ E.

Ex. 2. Taking the same course, viz., N.E. by E., where the variation is 1¼ points, *East*, and then the *compass* course (allowing easterly variation to the *left*) will be N.E. ¼ N.

Ex. 3. Suppose the *true* course to be S.E. by E., where the variation is 2¼ points *West*, the *compass* course (allowing variation to the *right*) will be S.S.E. ¾ E.

Ex. 4. But the same course, viz., S.E. by S., where the variation is 2¾ points *easterly*, will give the *compass* course (allowing easterly variation to the *left*) S.E. by E. ¾ E.

Taking the courses between *North* and *South* round by *West.*

Ex. 5. Let the *true* course be N.W. by W., where the variation is 2½ points *West*, then the *compass* course (allowing westerly variation to the *right*) will be N.N.W. ½ W.

Ex. 6. Suppose the course to be the same, viz., N.W. by W., where the variation is 2½ points *easterly*, the *compass* course (allowing easterly variation to the *left*) will be W. ½ N.

Ex. 7. With the *true* course *West*, and the variation 2 points *West*, then the *compass* course (allowing 2 points to the *right*) will be W.N.W.

Ex. 8. Taking the same course *West*, suppose the variation to be 2 points *East*, then the *compass* course (allowing 2 points to the *left*) is W.S.W.

Ex. 9. With the *true* course S.W. ½ S., where the variation is 2¼ points *West*, then the *compass* course (allowing westerly variation to the *right*) will be S.W. by W. ¾ W.

Ex. 10. But with the same course, viz., S.W. ½ S., where the variation is 1½ points *East*, the *compass* course (allowing easterly variation to the *left*) will be S.S.W.

119. Treating the points of the compass numerically, we proceed according to the following

RULE XXXVIII.

Proceed according to Rule XXXII, page 99, *in every particular, except that the variation is to be* allowed the **opposite way** *to that of correcting compass courses,* viz., Westerly *variation is to be allowed to the* **right** *and marked* R., *and* Easterly *variation is to be allowed to the* **left** *and marked* L.

Examples.

1. True Courses:—N.N.E.; S. by W. ½ W.; E. by N. ½ N.; W. by S. Var. 2½ W.

N.N.E.	S. by W. ½ W.	E. by N. ½ N.	W. by S.
2 R. of N.	1½ R. of S.	6½ R. of N.	7 R. of S.
2½ R.	2½ R.	2½ R.	2½ R.
4½ R. of N.	4 R. of S.	9 R. of N.	9½ R. of S.
N.E. ½ E.	S.W.	16	16
		7 L. of S.	6½ L. of N.
		E. by S.	W. by N. ½ N.

2. **True Courses**:—N.E. by E. ½ E.; S.W. by W.; E. by S. ½ S.; N.W. by W. Variation 3½ E.

N.E. by E. ½ E.	S.W. by W.	E. by S. ½ S.	N.W. by W.
5½ R. of N.	5 R. of S.	6½ L. of S.	5 L. of N.
3½ L.	3½ L.	3½ L.	3½ L.
2 R. of N.	1½ R. of S.	10 L. of S.	8½ L. of N.
N.N.E.	S. by W. ½ W.	16	16
		6 R. of N.	7½ R. of S.
		E.N.E.	W. ½ S.

3. **True Courses**:—N. by W. ½ W. and S. by E.; Variation 3¼ W. S. by W. and N. by E.; Variation 3¾ E.

N. by W. ½ W.	S. by E.	S. by W.	N. by E.
1½ L. of N.	1 L. of S.	1 R. of S.	1 R. of N.
3¼ R.	3¼ R.	3¾ L.	3¾ L.
1¾ R. of N.	2¼ R. of S.	2¾ L. of S.	2¾ L. of N.
N. by E. ¾ E.	S.S.W. ¼ W.	S.S.E. ¾ E.	N.N.W. ¾ W.

120. To convert **true course** into **correct magnetic course**, we may proceed according to the following

RULE XXXIX.

Westerly variation is + to all points between N. and E. ....S. and W.
Easterly variation is — from all points between N. and E. ....S. and W.
Westerly variation is — from all points between N. and W.....S. and E.
Easterly variation is + to all points between N. and W.....S. and E.

NOTE.—In applying this rule be careful to remember the precepts in Rule XXXIV, (a), (b), (c), and (d).

PLANE SAILING.

The figure for Plane Sailing is a right-angled triangle, as already explained, page 71 (see Fig. 14, page 71, and the foot note to same page), in which the vertical side (North and South line) represents the *difference of latitude.*

The horizontal side (East and West line) represents the *departure.*

The hypothenuse represents the *distance.*

The *angle* contained between the meridian and the distance represents the *course.*

Hence, all questions in Plane Sailing are merely solutions of *right-angled plane triangles.*

The two cases usually required in this sailing are:—

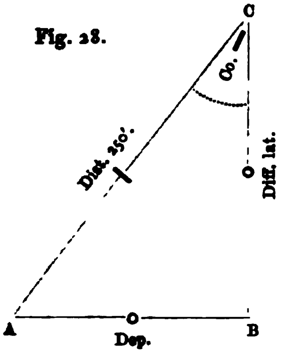
(1.) When the course and distance are given, to find the difference of latitude and departure.

(2.) When the difference of latitude and departure are given, to find the course and distance.

CASE I.

Ex. A ship sails S. 34° W. until her distance is 250 nautical miles: find the difference of latitude and departure she has made.

Fig. 28.



Given $\left\{\begin{array}{c}\text{Course S. 34° W.,}\\ \text{dist. 250 miles.}\end{array}\right\}$ to find $\left\{\begin{array}{l}\text{diff. lat.}\\ \text{and dep.}\end{array}\right.$

To find the diff. lat.

$\frac{BC}{AC}$, or $\frac{\text{diff. lat.}}{\text{dist.}}$ = cos. course.

∴ diff. lat. = dist. cos. course (1).

∴ log. diff. lat. = log. dist. + log. cos. co. — 10.

(1)

Log. dist.	250 =	2·39794
Log. cos. course	34° =	9·91857
Log. diff. lat.		2·31651

∴ Diff. lat. = 2073.

To find the dep.

$\frac{AB}{AC}$, or $\frac{\text{dep.}}{\text{dist.}}$ = sin. course.

∴ dep. = dist. sin. course (2).

∴ log. dep. = log. dist. + log. sin. co. — 10.

(2)

Log. dist.	250 =	2·39794
Log. sin. course	34° =	9·74756
Log. dep.		2·14550

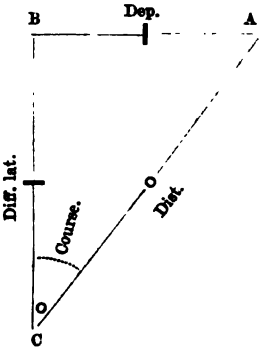
∴ Dep. = 139·8.

Note.—In every log. sin., log. cos., &c., the Tabular logarithm has 10 added to the *index,* and therefore 10 must be subtracted from the results above.

CASE II.

Ex. A ship makes 180 miles diff. lat. (northing), and 136 miles dep. (easting): find the course and distance.

Fig. 29.



$$\text{Given} \begin{cases} \text{diff. lat.} = 180 \\ \text{dep.} \quad = 136 \end{cases} \text{to find} \begin{cases} \text{course} \\ \text{and dist.} \end{cases}$$

To find the course.

$$\text{Tang. co.} = \frac{AB}{BC} = \frac{\text{dep.}}{\text{diff. lat.}} \quad (1)$$

∴ log. tang. co. — 10 = log. dep. — log. diff. lat.
or, log. tang. co. = 10 + log. dep. — log. diff. lat.

To find the dist.

$$\frac{AC}{BC}, \text{ or } \frac{\text{dist.}}{\text{diff. lat.}} = \text{sec. course.}$$

∴ dist. = diff. lat. sec. co. (2)
∴ log. dist. = log. diff. lat. + log. sec. co. — 10.

(1)

10 + Log. dep. 136 = 12·133539
Log. diff. lat. 180 = 2·255273

Log. tang. course 9·878266
∴ Course N. 37° 4′ E.

(2)

Log. diff. lat. 180 = 2·255273
Log. sec. course 37° 4′ = 10·098033

Log. dist. 2·353306
∴ Lat. 225·6 miles.

Examples for Practice.

1. A ship from lat. 54° 10′ N. sails N.W. by W., 256 miles: required her diff. lat., lat. arrived at, and dep. (See Case 1, page 109, and Rule XXVI, 1°, page 80.)

2. A ship from lat. 55° 1′ N. sails S.E. ½ E., 240 miles: find the lat. arrived at and dep. made. (See Case 1, page 109, and Rule XXVI, 2°, page 80.)

3. A ship sails N., 220 miles, and then W., 120 miles: required her course and dep. made good. (See Case 2, page 110.)

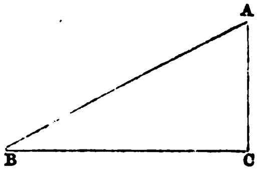
4. A ship sails from lat. 20° 40′ S. until she arrives in lat. 23° 54′ S., having made 140 miles of westing: required her course and distance made good.

THE TRAVERSE TABLE.

121. In all collections of tables for the use of navigators there is inserted a table called the "Traverse Table," containing the *true difference of latitude* and *departure*, corresponding to certain *distances* (at intervals of one mile) up to 300 nautical miles, for every course, at intervals of a quarter point, and also of degrees, from 0° to a right-angle (90°). Tables I and II (Raper or Norie). These Tables are so arranged that a given course and distance in it give the corresponding diff. lat. and dep.; and, conversely, with the given diff. lat. and dep. the course and distance are found—both operations by *Inspection*, that is to say, by merely looking into the Table, without employing any method of calculation.

This table is constructed by solving a right-angled triangle, of which one angle represents the course, and the hypothenuse the distance; by giving these different and successive values, the corresponding values of the other two sides are found, which sides represent the true difference of latitude and departure.

Fig. 30.



Thus, in the triangle C A B, right-angled at C: if the angle C A B represent a given course, and A B a given distance, the side A C will be the true diff. of lat., and B C the dep. corresponding to that course and distance.

Given course 30°, and distance 25 miles, compute corresponding true diff. lat. and dep. (See Case 1, Plane Sailing, page 109.)

In the triangle C A B, let $A = 30°$, and $AB = 26°$; then true diff. lat. $= AC = AB \times \cos. A = 25 \times \cos. 30°$, ∴ true diff. lat. $= 21'·65$, and dep. $= BC = AB \times \text{sine } A = 25 \times \text{sine } 30°$, ∴ dep. $= 12'·5$.

Inasmuch as the sine of an angle is the cosine of its complement (see page 43, Art. 53), it is evident that the difference of latitude and departure for any course are the dep. and diff. lat. for the complement of that course. Thus, let it be required to find the diff. lat. and dep. for course 60° and dist. 25 miles:—diff. lat. for $60° = 25 \times \cos. 60° = 25 \times \text{sine } 30°$ = dep. for 30°, and dep. for $60° = 25 \times \text{sine } 60° = 25 \times \cos. 30°$ = diff. lat. for 30°. When the diff. lat. and dep. are computed in this manner up to 45°, the diff. lat. and dep. for course *above* 45° may be found by changing the titles to the columns, and hence the table is compactly arranged by interchanging the headings of the columns containing these elements at the top and bottom of the page, and reading the top reading for courses from 0° to 45°, and the bottom reading for courses from 45° to 90°. This table may be used for a great number of problems depending for their solution on the relation of the several parts of a right-angled triangle, and since all the relations between any two quantities may be expressed as functions of some angle in terms of the sine, cosine, or tangent; it may be used, in fact, as a general proportional table.

The *Traverse Table* is generally given in two parts. I. To the *points of the compass;* and II. To *degrees.*

The *course* is found at the top of the Table, when under 4 points or 45°; but at the bottom of the Table, when it exceeds 4 points or 45°. The first column contains the *distance* to 60 miles, the second column contains the *difference of latitude*, expressed in minutes and tenths, and the third column, similarly expressed, contains the *departure;* but if the course exceeds 4 points, or 45°, the second column contains the *departure*, and the third column the *difference of latitude*. The other columns are a continuation of the former, exactly upon the same principle, and extending to 300 miles of distance. (See Tables I and II, Norie or Raper.)

USE OF THE TABLE.

122. Given the **course** and **distance,** to find the **difference** of **latitude** and **departure.**

RULE XI.

With the Course *open the Tables, and* under *or* above *the proper number of* points (*or* degrees), *and* opposite *the* distance, *will be found the* difference of latitude *and* departure.

Obs.—When the course is found at the bottom of the page, care must be taken to see that the diff. of lat. and the dep. are taken from the proper column *above* the words *departure* and *diff. lat.* It must be carefully remembered that when the course is *less* than 4 points or 45°, the *diff. lat. exceeds the dep.;* but when it is *more* than 4 points or 45° the *dep. exceeds the diff. lat.*

Examples.

Ex. 1. A ship sails N.W. ½ N. a distance of 78 miles: required the difference of latitude and departure by inspection.

The given course is 3½ points; and referring to Table I we find the page assigned to this course to be page 14, Norie, or page 436, Raper's Navigation, in which against 78, in column headed *dist.*, stands 60·3 under the head *lat.*, and 49·5 under the head *dep.* We conclude, therefore, that for the given course and distance, the difference of latitude is 60·3 miles, and the departure 49·5 miles.

Ex. 2. Suppose the course to be 5½ points, and the distance 98 miles.

Then, since the course here exceeds 4 points, we look for it at the foot of the page (page 10, Norie, or 432, Raper), and against 98 in the *distance* column we find in the adjacent column (marked at the bottom dep. and diff. lat.) *dep.* 86·4, and *diff. lat.* 46·2, so that the difference of latitude made is 46·2, and the departure 86·4.

Ex. 3. A ship sails N. 40° E., 50 miles: required the diff. of lat. and departure.

The course being less than 45°, is found at the top (Table II), and the distance being under 60 miles, is found in the left hand column; therefore, on the page (56 Norie) is 40° at the top, and opposite to 50 in the distance column (marked Dist.) is 38·3 *under* Lat., and 32·1 *under* Dep., the difference of latitude and departure required.

Ex. 4. A ship sails N. 64° W., 175 miles: required the diff. of lat. and departure.

The course being more than 45°, is found at the bottom, in page 42, and opposite to the distance 175 miles, is 76·7 *over* Lat., and 157·3 *over* Dep., which was required.

(a) To find diff. lat. and dep. when there are tenths in the distance.

Take the distance as an entire number *of miles,* i.e., as a whole number, *and find the corresponding* diff. lat. *and* dep., *from each of which cut off the right hand figure, or tenths, and remove the decimal point one place to the left hand, which will give the required* diff. lat. *and* dep. *in* miles *and* tenths *of a mile.** *The tenths, however, must be increased by* 1, *if the figure cut off is* 5, *or upwards.*

---

* The reason of this rule is that the Traverse Table is entered with a distance *ten times* as great as the given distance, and the resulting diff. lat. and dep. is divided by ten. This is done by merely imagining the decimal point to be removed one place to the *right* before entering the table, and then one place to the *left* after taking out the results (see p. 26, (10).

EXAMPLES.

Ex. 1. Course 3½ points, distance 20·3: required the diff. lat. and dep. corresponding thereto.

With course 3½ points, and dist. 20·3, taken as 203, we get the diff. of lat. 156·9, dep. 128·8; now cut off the right hand figure of each (the 9 and 8), and shifting the decimal point one place to the left, we have diff. lat. 15·7, and dep. 12·9. It will be observed that the tenths are increased by 1, in each case, as the figure cut off in both cases exceeds 5.

Ex. 2. Required the diff. lat. and dep. corresponding to course 4½ points, and dist. 24·3 miles.

With course 4½ points, and dist. 24·3 (as 243 miles), we find diff. lat. 154·2, and dep. 187·7: hence we obtain, after dropping the tenths, and removing the decimal point in each one place to the left, 15·4 and 18·8, for the required quantities. The tenths in the dep., it will be observed, are increased by 1, since the figure dropped exceeds 5.

Ex. 3. A ship sails N. 67° E., distance 29′·5: find diff. of lat. and dep. corresponding.

In this case take out for distance 295. Thus, for 67° and distance—

295 = 115·3 diff. lat., 271′·5 dep.
∴ 29·5 = 11·5 diff. lat., 27′·2 dep.

After dropping the tenths, and removing the decimal point one place to the left, we have diff. lat. 11·5 and dep. 27·2 (the tenths of dep. is increased by 1, as the figure cut off is 5.)

Ex. 4. N. 34° W., and dist. 20·6 miles (as 206), give diff. lat. 170·8, and dep. 115·2, dropping the tenths in each case (the 8 and the 2), and shifting the decimal point one place to the left, we get diff. lat. 17·1 N., and dep. 11·5 W. The tenths of diff. lat. must be increased by 1, as the figure cut off (8) exceeds 5.

(b) If the distance exceeds the limits of the Traverse Table.

Take the half, *the* third, &c., *so as to bring it within the limits,* taking care *to* multiply *the* corresponding quantities *by* 2, 3, &c.

Ex. 6. Let the course be 37°, and distance 435: required the corresponding diff. lat. and dep.

435 divided by 3 gives 145.

Course 37°, and dist. 145, give diff. lat. 115·8 and dep. 87·3
× 3 × 3
Diff. lat. 347·4 Dep. 261·9

If the distance had been 43·5, the diff. lat. would have been 34·7, and the dep. 26·1.

(c) But when the distance is between 300 and 600 we may proceed as follows:—

Take out diff. of lat. and dep. for 300, *and for the* excess *of* 300; *take the* sum *of the quantities thus found, cut off the last* figure, *and* remove *the* decimal point *as before.*

Ex. 7. Course 65°, and distance 526: required the corresponding diff. of lat. and dep.

Course 65°, and dist. 300, give diff. lat. 126·8, and dep. 271·9
226 95·5 204·8
526 222·3 476·7

If the distance were 52·6 we should proceed as above, and then cutting off the last figure of each, and removing the decimal point one place to the left, the diff. of lat. is 22·2, and dep. 47·8. The tenths are increased by 1 in the last case of dep., as the figure cut off in one exceeds 5.

Examples for Practice.

In each of the following examples find the difference of latitude and departure corresponding to the given course and distance:—

	Given.			Given.	
No.	Course.	Dist.	No.	Course.	Dist.
1.	S.S.E.	30	8.	S. 72° W.	35
2.	E. by S.	48	9.	N. 21 W.	24·5
3.	S.W. ¼ S.	136	10.	S. 65 W.	25·7
4.	W. ¾ N.	84	11.	S. 80 W.	14·7
5.	S.E. by E. ¼ E.	56	12.	N. 27 W.	30·6
6.	S.W. ½ W.	225	13.	W. 10 S.	42·8
7.	E. by N. ¼ N.	183	14.	N. 18 W.	34·9

123. Given the **difference of latitude and departure,** to find the **course** and **distance.**

RULE XLI.

Seek in the Traverse Table (Table II) till the *diff. lat. and dep., or the quantities agreeing most nearly with them, are found* opposite *each other in the proper columns; to the left or abreast of the quantities thus found, and* under "Dist.," *will be the distance made good; and the* Course *(in degrees) must be taken from* the top of the page *when* diff. lat. *is* greater *than the* dep.; *but from the* bottom of the page *when the* dep. *is* greater *than the* diff. lat.

The Course *will have the* same name (from N. or S. towards E. or W.) *as the* diff. lat. *and* dep. *made good.*

Note.—Always seek for the larger of the two given numbers in the column next the distance, viz., the column marked "Diff. Lat." at the top, and examine page after page, until the smaller number is found by its side in the column marked "Dep." at the top; being careful to *remember that* when diff. lat. *is* greater *than the* dep. the course *will be at* the top; otherwise *it is to be found* at the bottom.

(a) When the diff. lat. and dep. on two successive pages of the Traverse Table, appear to be equally near the given diff. lat. and dep., neither page giving values actually corresponding to them, take a course midway between those on the two successive pages as the course actually made good.

(b) If the difference of latitude and departure, or any of the sides of the proposed triangle, should exceed the limits of the Traverse Table, they may be divided by any number that will bring them within these limits, and then the results from the Table multiplied by the same number will give the required parts of the proposed triangle; observing that the **angle or course must in no case be multiplied or divided,** because the **course** will be the **same,** whether determined to the whole difference of latitude or departure, or by using an aliquot part of the same.

(c) In certain extreme cases, as when diff. lat. and dep. are very small, the course cannot be found correctly as above, since the diff. lat. and dep. may be found to agree in their respective columns for several successive pages of the table. In such cases, the diff. lat. and dep. may be multiplied by 10, and the products, when found to agree in their respective columns, will give the correct course; but the distance from the table, divided by 10, will give the correct distance.

EXAMPLES.

Ex. 1. A ship having sailed between the N. and E., until her difference of latitude is 199 miles, and the departure 144·6: required her course and distance.

In page 52, Norie, or page 474, Raper, these quantities will be found to correspond with 246 in the distance column, and with the angle 36° found at the *top* of the table (the diff. lat. being greater than dep.); the course is therefore N. 36° E., and distance 246 miles.

Ex. 2. A ship has made upon one course 36 miles diff. lat. to the northward, and 58 miles dep. to the westward: required the course and distance run.

Look for 58 and 36 in two adjoining columns marked "diff. lat." and "dep." at the top. In the table will be found 57·7 and 36·0 abreast of each other. In the same line at the dist. column will be found 68, the distance sought. As 58, the dep., is greater than diff. lat. 36, the course is taken from the bottom of the page. It is 58°. As the ship has gone to the N. and W., the course she has made is N. 58° W.

Ex. 3. A ship having sailed betwen S. and W. until her difference of latitude is 40 miles, and her departure 139·4 miles: required the course and distance.

In page 32, Norie, or page 454, Raper, the course answering to *diff. latitude* 40 miles, and *departure* 139·4 miles, corresponds with the angle 74°, at the bottom of the table, and opposite the distance 145 miles; the course is therefore S. 74° W., and distance 145 miles, which were required.

Ex. 4. Given the diff. lat. 240'·0 S., and dep. 208·6 E.; required the corresponding course and distance. (See Rule XLI, (b), page 114.)

As both diff. lat. and dep. exceed the limits of the table, divide them by 2, so as to bring them within these limits, thus:—

Diff. lat.	Dep.
2)240·2	2)208·8
120·1	104·4

Then seeking for 120·1 and 104·4 in two adjoining columns marked "diff. lat." and "dep." at the top. In the Table are found 120'·0 and 104·3 abreast of each other. In the same line in the distance column will be found 159, which must be multiplied by 2 (the number the diff. lat. and dep. were divided by), the product 318 is the distance sought. As 120·1, the diff. lat., is greater than the dep., the course is taken from the top of the page. It is 41°. As the ship has gone to the S. and E., the course she has made is S. 41° E.

Ex. 5. Given diff. lat. 1'·0 and dep. 0'·1: to find the corresponding course and distance.

Here diff. lat. 1'·0 and dep. 0'·1 are found in tables to give as course 3°, 4°, 5°, 6°, 7°, and 8°; now which is the correct answer in this case?

Multiplying diff. lat. and dep., say by 10, we obtain diff. lat. 10'·0 and dep. 1'·0; these are found in the tables to correspond to course 6° and distance 10 miles. Dividing the distance by 10 gives 1 (dividing by 10 as the tables were entered with *ten* times the diff. lat. and dep.), hence course 6° and distance 1 mile.

EXAMPLES FOR PRACTICE.

In each of the following examples the difference of latitude and departure are given, to find the corresponding course and distance.

	Given.			Given.	
No.	Diff. Lat.	Dep.	No.	Diff. Lat.	Dep.
1.	72·7 S.	25·0 E.	6.	37·9 N.	36·4 E.
2.	72·3 N.	171·7 E.	7.	53·3 S.	76·0 W.
3.	64·0 N.	146·9 W.	8.	160·7 S.	16·5 W.
4.	98·6 S.	37·5 E.	9.	172·6 S.	7·9 W.
5.	415·6 N.	240·0 W.	10.	164·2 N.	262·8 E.

TRAVERSE SAILING.

124. Traverse Sailing is the case in plane sailing when the ship makes several courses in succession, the track being zigzag, and the direction of its several parts "traversing," or lying more or less athwart of each other. For all these actual courses and distances run on each, a single equivalent imaginary course and distance may be found, which the ship would have described had she sailed direct for the place of destination. Finding this course is called "Working a Traverse."

In order to do this, the difference of latitude and departure for each distinct course must be found, and the agregate of the several differences of latitude and departure taken for the single difference of latitude and departure which would be made by sailing from the place left to that reached on a single course. The determination of this course, and the corresponding distance, is then to be effected.*

125. In resolving a traverse, it is usual to take the diff. lat. and the dep. due to each of the component courses from the Traverse Table; hence we proceed by the following

RULE XLII.

1°. *Draw out a form similar to that given in the following example.*

2°. *In the column headed* Courses, *enter each course in succession; and in column* Dist., *enter the distance run on each course.*

In entering the courses in the appropriate column, reckon, in each case, the points, and fractional parts of a point, from the North or South, whichever is nearest, and write them down as in the following example.

3°. *Take out of the* Traverse Tables (Table I or II, Raper or Norie), *the difference of latitude and departure to each course and distance, and enter the latitude in column* N. *or* S., *and the departure in column* E. *or* W., *according to the name of the course.*

Thus, if the course is S.E. by S., the difference of latitude must be entered in the column S., and the departure in the column E.; if the course is W. ¼ N., the difference of latitude must be entered in the column N., and the departure in the column W.

3*a*. *When the course is* exactly North or South, *the distance and diff. lat. are the same, there is* no departure, *and the whole* distance *is entered as* difference of latitude *in the corresponding column* N. *or* S., as the case may be; *so also when the course is due* East *or* West, *the* departure *is* identical *with the* distance, *there is* no difference of latitude, *and the* whole distance *run is entered as* departure *in the* E. *or* W. *column*. (See pages 118-119, Exs. 2, 3, and 5.)

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* The plane sailing formula—

$$\text{Dep.} = \text{Dist.} \times \text{Sine course} \quad (1)$$
$$\text{D. Lat.} = \text{Dist.} \times \text{Cos. course} \quad (2)$$

give for each course and distance the corresponding departure and difference of latitude; and taking the algebraic sum of all the diff. lats. and dep., we get the course from formula

$$\text{Tang. course} = \frac{\text{Dep.}}{\text{D. Lat.}}$$

and then the distance from formulæ (1) and (2). But such computations are tedious and unnecessary, and the *Traverse Table*, which gives these by Inspection, is used to obviate the necessity of computations.

4°. Add *the diff. of lats. in each column, and write the sum at the bottom of each, write the* less *of the two sums under the* greater, *and take their* difference. *Do the same with the departure.*

5°. *These differences are the* diff. lat. *and* dep. *made good on the whole, and each takes the* name *of the* column *it stands in.*

6°. The course and distance are then found by Rule XL, page 112.

Note.—(*a*). When there is no resulting departure the Traverse Table need not be referred to, as the ship has returned to the same meridian, and the course made good is North (N.) or South (S.), according as the diff. lat. is North or South, and the distance is equal to the diff. lat. (See Example 5, page 119.)

(*b*). Similarly, when there is no resulting difference of latitude, the course made good will be either East (E.) or West (W.) as the departure made good is East or West, and the distance will be of equal value with the difference of departures. (See Ex. 4, page 119.)

(*c*). Should the difference of latitudes and also the departures balance each other, in which case the ship will have made good neither difference of latitude nor departure, the vessel must be considered to have returned to the place from which she set out.

It may be advisable for a beginner, before he proceeds to take out the quantities from the Traverse Tables, to write a *dash* in all the places *not* to be occupied by a difference of latitude or departure, in order to avoid writing a quantity in the wrong column. Such helps, however, are useless to an expert computer.

Examples.

Ex. *1*. A ship from the Dudgeon Light, in lat. 53° 19′ N., sails S.S.E. ¼ E., 8 miles; E.N.E., 23 miles; N.W. by W. ½ W., 36 miles; E. ¾ N., 48 miles; and N.W. ½ W., 46 miles: required the latitude arrived at, also the course and distance made good.

Courses.	Dist.	Diff. Lat.		Departure.	
		N.	S.	E.	W.
S.S.E. ¼ E. .... = S. 2¼°E.*	8	—	7·2	3·4	—
E.N.E. .... = N. 6 E.	23	8·8	—	21·3	—
N.W. by W. ½ W. = N. 5½ W.	36	17·0	—	—	31·8
E. ¾ N. .... = N. 7¼ E.	48	7·0	—	47·5	—
N.W. ½ W. .... = N. 4½ W.	46	29·2	—	—	35·6
* The courses are given in this double form merely as an illustration of the method of using them.		62·0 7·2	7·2	72·2 67·4	67·4
		54·8		4·8	

Table I, Raper, and Table I, Norie. (See explanation below.)

Explanation.—The courses and distances are entered in their proper columns, in the same order as they stand in the question; then in Traverse Table I, Norie or Raper, the diff. lat. and dep. to each course and distance is found and entered in their proper column. (See Rule XLII, 3°).

The sum of the respective columns, N., S., E., and W., is next found, and set down at the bottom of each column, and the difference between the Northing, viz, 62·0, and the Southing, viz., 7·2, is taken, which leaves 54·8 N., which is the Diff. lat. made; the difference between the Easting 72·2, and Westing 67·4, leaves 4·8 E., departure.

We proceed in the next place to find the course and distance made good, thus:—

In Traverse Table II. { Diff. lat. 54·8 N. and dep. 4·8 E. } give { Course N. 5° E. Dist. 55 miles. } made good.

This is an illustration of the remark, that when the diff. lat. is more than the dep., the course is less than 4 points, or 45° (see Rule XLI, page 114), and it is named from the N. towards the E., since the diff. lat is N. and the dep. E.

Lat. left (or sailed from) Dudgeon Light	53° 19′ N.	Lat. in is found according to Rule XXVI, 1°, page 80.
Diff. lat. 54·8	= 55 N.	
Lat. in (or arrived at)	54 14 N.	

Ex. 2. A ship from Cape Espicheli, in lat. 38° 25′ N., sails as follows: S.W. by W., 28 miles; W. by N., 55 miles; West, 47 miles; S.E. ¾ S., 25 miles; South, 101 miles; W. ¾ S., 72 miles: required the latitude in, also the course and distance made good.

Courses.	Dist.	Diff. Lat.		Departure.	
		N.	S.	E.	W.
S. 5° W.	28	——	15·6	——	23·3
N. 7 W.	55	10·7	——	——	53·9
W.*	47	——	——	——	47·0
S. 3¼ E.	25	——	20·1	14·9	——
S.*	101	——	101·0	——	——
S. 7¼ W.	72	——	10·6	——	71·2
* See Rule XLII, 3*a*, page 116.		10·7	147·3	14·9	195·4
			10·7		14·9
			136·6		180·5

We seek in the Traverse Table till the diff. of lat. 136·6, and dep. 180·5, are found opposite each other, in their respective columns; the nearest to these are 180·5 and 136·0, which give the course (at the bottom of page, dep. being the most) S. 53° W., and distance 226′. This is an illustration of the remark in Rule XLI, page 114, that when the departure exceeds the difference of latitude, the course is more than 45°.

Lat. left 38° 25′ N.
Diff. lat. 136·6 = 2 17 S.
Lat. in (or arrived at) 36 8 N.

The lat. in is found according to Rule XXVI, 2°, page 80.

Ex. 3. A ship from lat. 37° 24′ S., sails the following true courses:—S.W. by S., 20 miles; West, 16 miles; N.W. by W., 28 miles; S.S.E., 32 miles; E.N.E., 14 miles; S.W., 36 miles: required the lat. in, also the course and distance made good.

Courses.	Dist.	Diff. Lat.		Departure.	
		N.	S.	E.	W.
S. 3° W.	20	——	16·6	——	11·1
W.*	16	——	——	——	16·0
N. 5 W.	28	15·6	——	——	23·3
S. 2 E.	32	——	29·6	12·3	——
N. 6 E.	14	5·4	——	12·9	——
S. 4 W.	36	——	25·5	——	25·5
* See Rule XLII, 3*a*, page 116.		21·0	71·7	25·2	75·9
			21·0		25·2
			50·7		50·7

We seek in the several pages of the Traverse Table II, for the diff. lat. 50·7; and dep. 50·7; the nearest found to these are diff. lat. 50·9, dep. 50·9, give course S. 45° W., distance 72 miles.

The diff. lat. and dep. being of equal amount, the course is 45°, or 4 points.

Lat. left 37° 24′ S.
Diff. lat. 50·7 = 51 S.
Lat. arrived at 38 15 S.

The lat. sailed from being South, and the ship having sailed South, the ship has evidently increased her South lat., whence the sum of lat. from and diff. lat. is taken to obtain lat. in.—(See Rule XXVI, 1°, page 80.

Ex. 4. A ship from lat. 46° 20′ N., sails (all true courses) N. 72° E., 21 miles; N. 38° E., 17 miles; S. 26° W., 13 miles; S. 73° E., 19 miles; S. 1° W., 19 miles; S. 65° E., 48 miles; N. 76° E., 19 miles; N. 48° E., 48 miles: required the lat. in, also the course and distance made good.

Courses.	Dist.	Diff. Lat.		Departure.	
		N.	S.	E.	W.
N. 72° E.	21	6·5	—	20·0	—
N. 38 E.	17	13·4	—	10·5	—
S. 26 W.	13	—	11·7	—	5·7
S. 73 E.	19	—	5·6	18·2	—
S. 1 W.	19	—	19·0	—	0·3
S. 65 E.	48	—	20·3	43·5	—
N. 76 E.	19	4·6	—	18·4	—
N. 48 E.	48	32·1	—	35·7	—
		56·6	56·6 56·6	146·3 6·0	6·0
				140·3	

Course due East, and dist. 140·3, the same as the departure. (See Rule XLII, 6°, Note (*b*), page 117).

The Traverse Table being filled up, the sums of the Northings and Southings are both 56·6, and being of contrary directions, show that the ship has returned to the same parallel of latitude which she sailed from. The sum of the Eastings is 146·3, and that of the Westings 6·0; their difference, 140·3, shows that the ship has gained so much to the Eastward, that being the greater. Consequently the *Course* is due *East*, and the *Distance* 140·3, the same as the departure.

Ex. 5. A ship from a place in lat. 1° 5′ S., sails the following true courses:—N. 17° E., 13 miles; North, 38 miles; N. 27° E., 18 miles; N. 79° E., 25 miles; S. 83° W., 23 miles; S. 48° E., 25·2 miles; N. 48° W., 27·1 miles; N. 36° W., 21 miles: required the latitude in, also the course and distance made good.

Courses.	Dist.	Diff. Lat.		Departure.	
		N.	S.	E.	W.
N. 17° E.	13	12·4	—	3·8	—
North*	38	38·0	—	—	—
N. 27 E.	18	16·0	—	8·2	—
N. 79 E.	25	4·8	—	24·5	—
S. 83 W.	23	—	2·8	—	22·8
S. 48 E.	25·2	—	16·9	18·7	—
N. 48 W.	27·1	18·1	—	—	20·1
N. 36 W.	21	17·0	—	—	12·3
* See Rule XLII, 3*a*, page 116.		106·3 19·7	19·7	55·2 55·2	55·2
		86·6			

The Traverse Table being completed, the sum of the Northings is 106·3, and the sum of the Southings is 19·7, the difference 86·6, and to that amount the ship has altered her latitude. The miles of departure in the East are 52·2, and those in the West column are also 52·2; but as the East and West departures destroy one another, there is no resulting departure, and therefore it is not necessary to refer to the Traverse Table. The ship is under the same meridian as she sailed from; consequently, the course is due North, and the distance sailed is equal to the diff. lat., viz., 86·6. This is according to Rule XLII, 6°, Note (*a*), page 117.

Latitude left 1° 5′ S.
Diff. lat. 6,0)8,6·6
1 26·6 = 1 27 N.
Latitude in 0 22 N.

The ship being 1° 5′, or 65 miles, S. of the equator, must evidently be in N. lat. after making 87 miles of Northing. Thus, in subtracting one of the quantities from the other, the difference takes the *name* of the greater. Rule XXVI, page 80.

The course is North, and dist. 86·6, the same as diff. lat.

EXAMPLES FOR PRACTICE.

1. A ship from the Texel in lat. 52° 58′ N., sails W. by N., 44 miles; S. by E., 45 miles; W. by S., 35 miles; S.S.E., 44 miles; W.S.W. ½ W., 42 miles: find diff. lat. and dep., the course and dist. made good, also the lat. arrived at.

2. A ship from Heligoland, lat. 54° 12′ N., sails W.S.W., 12 miles; N.W., 24 miles; S. by W., 20 miles; N.W. by W., 32 miles; S. by E., 36 miles; W. by N. ½ N., 42 miles; S.S.E. ½ E., 16 miles; W. ¾ N., 45 miles: required diff. lat. and dep., course and dist. made good, also the lat. arrived at.

3. A ship sails from lat. 3° 50′ N., sails S.S.W., 112 miles; S. by E., 86 miles; S.S.E., 112 miles; S. by W., 86 miles: find diff. lat. and dep., the course and dist. made good, also the lat. arrived at.

4. Yesterday we were in lat. 19° S., and since then have sailed S.E. ½ S., 13 miles; S. by E., 19 miles; S.E. by E., 22 miles; E. by S. ¼ S., 32 miles; N.N.E., 20 miles; N. by W. ¼ W., 27 miles; N.E. by E. ½ E., 24 miles; S.W. ¼ S., 10 miles.

5. A ship from lat. 1° N., sails East, 8 miles; E. ¼ N., 20 miles; S.E. by E., 33 miles; S. ¾ W., 31 miles; N.E. ½ N., 43 miles; South, 28 miles; S. ¾ E., 21 miles; S. by W. ¼ W., 12 miles: required diff. lat. and dep., course and dist. made good, and also the lat. in.

6. A ship from lat. 1° 10′ N. sails N. 40° W., 20 miles; S. 56° W., 51 miles; S. 19° W., 19 miles; S. 48° W., 16 miles; N. 85° E., 28 miles; S. 44° E., 15 miles; N. 22° W., 25 miles; S. 9° E., 54 miles: find diff. lat. and dep., course and dist. made good, also the lat. in.

7. A ship from lat. 47° 12′ N. sails S. 31° W., 16 miles; N. 72° E., 13′·1; S. 52° W., 15′; S. 44° E., 15′·1; N. 44° W., 19′·7; N. 77° E., 11′·4; S. 40° W., 16′; S. 14° E., 6′: required the course and dist. made, the lat. arrived at, and the dep. made.

8. Since leaving lat. 34° 11′ N. we have sailed the following courses:—N. 36° W., 27′; N. 24° E., 30′; S. 75° W., 47′; S. 80° W., 29′; N. 72° W., 42′; N. 78° W., 34′; S. 12° E., 28′: required the course and dist. made, the lat. arrived at, and the dep. made.

9. Since leaving lat. 36° 35′ S. the ship has sailed N. 84′ W., 18′; N. 89° W., 30′·4; N. 67° W., 29′·9; N. 39° W., 33′·9; N. 8° W., 25′·9; N. 73° W., 34′·9; N. 86° W., 44′·7; S. 65° E., 56′: required the lat. arrived at, and the course and dist. made good.

PARALLEL SAILING.

126. When two places on the same parallel of latitude, or due East or West of each other, the distance between them, estimated along a parallel, or E. and W. (which is all departure), is converted into *difference* of longitude; or, on the other hand, the **difference of longitude** is converted into **distance** by **Parallel Sailing.**

Since the meridians are all parallel to the equator and meet at the poles, the distance between any two meridians, measured East and West, is less as the latter is greater—that is, the *absolute number of miles*, or of feet, in a degree of longitude is less as the latitude in which they are measured is greater. Hence, also, a given number of miles between two meridians correspond to a greater difference of longitude, as the latitude in which they are measured is greater. For example, two places in lat. 10° and distance 60 miles East and West from each other, have 60'.9 diff. long. In lat. 60° N. or S., two places similarly situated have 2° 0' diff. long., while at 73° the diff. long. is 3° 25'. Questions of this kind are solved by Parallel Sailing.

In this sailing then a ship's track is supposed to be on a *parallel of latitude*, as from A to B (see Fig. 31, page 122). The latitude of A or of B is represented by A D or B L.

The *diff. long.* between A and B is the arc of the equator, D L.

The arc A B is the *departure* (or meridian distance) between A and B.

BY SPHERICAL TRIGONOMETRY

It may be proved that

$$\frac{\text{The arc AB of the parallel}}{\text{The arc DL of the equator}} = \text{cos. AD or cos. BL (see Fig. 31)},$$

$$\text{that is, } \frac{\text{dep.}}{\text{diff. long.}} = \text{cos. lat., whence the following formulæ.}$$

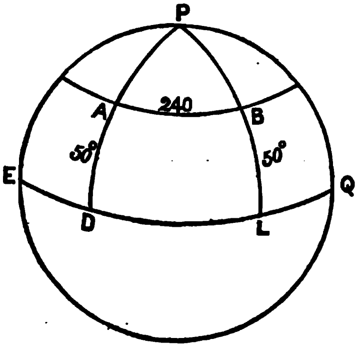
A	$\frac{\text{dep.}}{\text{diff. long.}} = \text{cos. lat.}$ $\therefore \text{dep.} = \text{diff. long. cos. lat.}$	When the lat. of the parallel and diff. long. between the two places are given; to find the dep. (or mer. dist.) between the two places.
B	$\frac{\text{diff. long.}}{\text{dep.}} = \text{sec. lat.}$ $\therefore \text{diff. long.} = \text{dep. sec. lat.}$	When the dep. (or mer. dist.) between the two places and the lat. of the parallel are given: to find the diff. long. between the two places.
C	$\text{cos. lat.} = \frac{\text{dep.}}{\text{diff. long.}}$	When the dep. (or mer. dist.) and diff. long between the two places are given: to find the lat. of the parallel on which the two places are situated.

CASE A.

127. Given the departure made good on a given parallel of latitude, to find the difference of longitude corresponding thereto.

EXAMPLES.

Fig. 31.



Given AB = dep. (or mer. dist.) = 240 miles

AD = BL = Lat. 50°

To find DL = required diff. long. (See Ex. 1.)

$$\text{Then } \frac{\text{D L}}{\text{A B}} = \text{sec. A D},$$

$$\text{or, } \frac{\text{diff. long.}}{\text{dep.}} = \text{sec. lat.}$$

$$\therefore \text{diff. long.} = \text{dep.} \times \text{sec. lat.}$$

$$\text{log. diff. long.} = \text{log. dep.} + \text{log. sec. lat.} - 10^\circ$$

Hence

RULE XLIII.

1°. *Take out of the Tables* (XXIV, NORIE, or 67, RAPER) *the log. of the departure, and the log. of secant of the latitude* (Table XXV, NORIE, or Table 68, RAPER).

2°. *Add these logs. together and find the natural number corresponding thereto* (XXIV, NORIE, or 67, RAPER): the result is the diff. of longitude required.

Ex. 1. A ship in the parallel of 50° N. latitude makes 240 miles of departure: find the corresponding difference of longitude.

Log. dep.	240 =	2·380211
Log. sec. lat.	50° =	10·191933
Log. diff. long.	=	2·572144

∴ diff. long. = 373·4.

By Inspection.

RULE XLIV.

With the latitude of the parallel as a Course, *and the dep. as* diff. lat., *enter the Traverse Table, and the corresponding* distance *will be the* diff. long. *required.*

EXAMPLE (above).—Entering the Traverse Table with 50° as *Course*, and one-half the departure 120 (the whole dep. 240 being too large for the Tables) as *diff. lat.*, the corresponding dist. 187 multiplied by 2 = 374 will be the *diff. long.* required.

Ex. 2. In lat. 71° 25′ N., the dep. made good was 71¼ miles: required the diff. of long.

Lat. 71° 25′	Secant	0·496640
Dep. 71·25	Log.	1·852785
	Log.	2·349425

Diff. of long. 223·6 nearly.

Ex. 3. In lat. 80°, the dep. made good was 80 miles: required the diff. of long.

Lat. 80°	Secant	0·760330
Dep. 80	Log.	1·903090
	Log.	2·663420

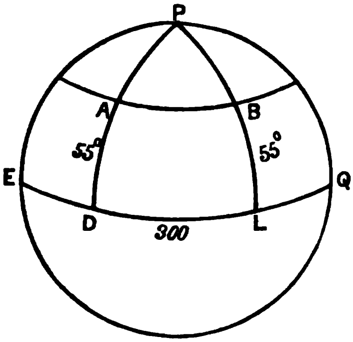
Diff. of long. 460·7.

CASE B.

128. Given the difference of longitude of two places on the same parallel, to find their distance as measured along the parallel.

Examples.

Fig. 32.



Given A D = B L = Lat. 55°

D L = diff. long. = 300 miles.

To find A B = required dep. (or mer. dist.)

$$\text{Then } \frac{\text{A B}}{\text{D L}} = \text{cos. A D}$$

$$\therefore \frac{\text{dep.}}{\text{diff. long.}} = \text{cos. lat.}$$

$$\therefore \text{dep} = \text{diff. long.} \times \text{cos. lat.}$$

$$\therefore \text{log. dep.} = \text{log. diff. long.} + \text{log. cos. lat.} - 10.$$

RULE XLV.

To the log. of the diff. of long. add the cosine of lat.: the sum (rejecting 10) *is log. of the distance required.*

Ex. 1. A ship on the parallel of 55° N. (or S.) latitude makes 300 miles diff. of longitude: find the corresponding departure (or meridian distance).

Log. diff. long. 300 = 2·477121
Log. cos. lat. 55° = 9·758591

Log. dep. = 2·235712
∴ Dep. (or mer. dist.) = 172·1.

By Inspection.

RULE XLVI.

With the latitude of the parallel as Course, *and the* diff. long. *as* distance, *enter the Traverse Tables, and the corresponding* diff. lat. *will be the* departure *required.*

Ex. (above). Entering the Traverse Table with 55° as a *Course*, and 300 in dist. column, the corresponding *diff. lat.*, 172·1, will be the corresponding *dep.* required.

Ex. 2. Required the distance between St. Abb's Head, in latitude 55° 55′ N., longitude 2° 10′ W., and Uraniberg in the same latitude, but in longitude 12° 52′ E.

Longitude of St. Abb's Head 2° 10′ W.
Longitude of Uraniberg 12 52 E.

15 2
60

Difference of longitude 902 miles.

Log. distance = log. diff. long. + log. cosine lat. — 10.

Log. diff. long. 902 = 2·955207
Log. cos. lat. 55° 55′ = 9·748497

Log. distance 505′·5 = 2·703704

CASE C.

129. Given the meridian distance and difference of longitude: to find the latitude.

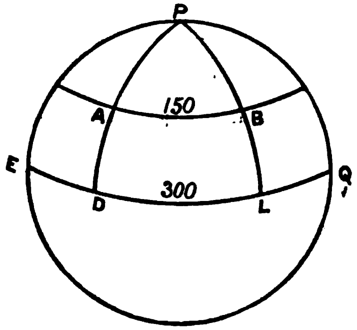
RULE XLVII.

From the log. of meridian distance or dep. (adding 10 to the index) *subtract the log. of diff. long.: the remainder is log. cosine of* latitude.

EXAMPLES.

Ex. 1. On what parallel of latitude must a ship sail 150 miles due East or West to change her longitude 300.

Fig. 33.



Given A B = dep. (or mer. dist.) = 150 miles

D L = diff. long. = 300 „

To find A D = B L = latitude required.

Then $\cos. \text{lat.} = \frac{\text{dep.}}{\text{diff. long.}}$

∴ Log. cos. lat − 10 = log. dep. − log. diff. long.

or, Log. cos. lat = 10 + log. dep. − log. diff. long.

10 + log. dep.	150 =	12·176091
Log. diff. long.	300 =	2·477121
Log. cos. lat.		9·698970

∴ Latitude of parallel = 60°.

By Inspection.

RULE XLVIII.

With the diff. long. as distance, *and the* dep. *as diff. lat., enter the Traverse Table, and the corresponding* Course *will be the* latitude required.

Ex. (above). Entering Traverse Table with 300 as *distance*, and 150 (or the nearest number to it) as *diff. lat.*, the corresponding course, 60°, will be the latitude required.

Ex. 2. From a place in longitude 3° 12′ W., a ship sails due East 246 miles, and by observation is found to be in longitude 4° 8′ E.: required the latitude of the parallel on which she sailed.

By Calculation.

$\text{Cos. lat.} = \frac{\text{mer. dist.}}{\text{diff. long.}}$

Long. left	3° 12′ W.
Long. in	4 8 E.
D. long.	7 20 = 440 miles.

Mer. dist. 246	log. (+ 10)	12·390935
Diff. long. 440	log.	2·643453
Lat. 56° 0′	cos.	9·747482

By Inspection.

Since the diff. long. given, 440, exceeds the distance given in the Traverse Table, its half is taken, and also the half of the meridian distance 246, these are 220 and 123 respectively. Entering the Tables with 220 as distance, and 123 as diff. lat., we find, on searching the Tables, these quantities, in their respective columns, on the page with 56° at the bottom; hence the latitude sought is 56°.

We can solve these problems by constructing a right-angled triangle in which the base represents the departure, the angle at the base the *latitude* of the parallel, and the hypothenuse represents the *difference of longitude.*

EXAMPLES FOR PRACTICE.

1. Two ships in 60° S. are 200 nautical miles apart: what is their diff. long.? (See Ex. 1, page 122.)

2. How much longitude will a ship run down in a day when in the latitude of Cape Horn 55° 59′ S., if she sails due West at the rate of 10 knots per hour. (Ex. 2, page 122).

3. The difference of longitude between two ships is 500 miles, and the meridian distance is 250: what parallel are they on? (See Ex., page 124).

4. What is the length of a degree (in nautical miles) on the parallel of 70°.

5. In what latitude must a ship be that each mile of departure (meridian distance) shall be equal to two miles of longitude?

6. A ship on the parallel of 55° N. sails due East, from long. 35° 30′ W. to long. 25° 30′ W.: find the meridian distance (dep.) she has made. (See Ex., page 123).

7. Two vessels leave Fayal in lat. 38° 32′ N., long. 28° 38′ W., bound to Halifax, lat. 44° 40′ N., and long. 63° 35′ W.; one sails *due* North until she is in the latitude of Halifax, and then steers *due* West until she reaches it; the other sails *due* West until she is in long. of Halifax, and then steers *due* North until she reaches it: which will arrive there first, if they both sail at the same rate? and how many miles will she gain on the other?

8. A and B lie on the parallel of 58° 30′ N.

Given long. A 15° 12′ E.
B 13 18 W.

What is the distance between them in nautical miles? (See Ex. 2, page 123).

9. In what latitudes are the lengths of a degree of longitude 30 and 20 miles respectively?

10. In travelling 35 nautical miles on the parallel of 55° 25′ N., how much do I change my longitude? (See Ex. 1, page 122).

11. Find the true course and distance from A to B.

Lat. A 54° 25′ S.; long. A 15° 30′ E.
B 54 25 S.; B 9 15 W.

12. Two ships in latitude 41° 18′ N., distant apart 150 miles, both sail due North until they are 50 miles apart. In what latitude are the vessels then?

13. How far must a ship sail due East in latitude 70° to change her longitude 5°.

MIDDLE LATITUDE SAILING.

130. Middle Latitude Sailing is a method founded on the principle of parallel sailing, of converting Departure into Difference of Longitude, and the Difference of Longitude into Departure, when the ship's course lies obliquely across the meridian, that is, when besides departure she makes difference of latitude.

Suppose a ship, in going on the same course, from latitude 40° to latitude 44°, make 100 miles departure: this departure, if made good altogether in latitude 40°, would give 130·5 difference of longitude by Rule XLIII, page 122; and again, if made good in latitude 44°, it would give 139 difference of longitude. Now, since the ship has sailed between these two parallels, and not on either of them exclusively, her real difference of longitude must be between 130·5 and 139, and, therefore, we may conclude it to be not far from that which would result from a departure made good altogether in the *middle parallel;* hence the name *Middle Latitude Sailing.* Middle latitude sailing, then, is founded on the consideration that the arc of the parallel of middle latitude of two places intercepted between their meridians is nearly equal to the departure. If we conceive the ship to sail along this middle parallel, we may apply the principle of *parallel sailing* to the cases in point. In parallel sailing, as has been shown, the departure (or distance) and difference of longitude are connected by the relation, dep. = diff. of long. × cos. lat. When the ship's course lies obliquely across the meridian, making good a difference of latitude, a modification of this formula gives the formula for middle latitude sailing, dep. (nearly) = diff. of long. × cos. mid. lat.; or in logarithms, log. dep. = log. diff. of long. + log. cos. mid. lat. — 10. Middle latitude sailing has thus the same two cases as parallel sailing, and accordingly the rules for inspection and computation already given, Rules XLIII, XLV, and XLVII, pages 122, 123, and 124, apply equally to this sailing, observing merely to read *middle latitude* for *latitude.*

The two cases most commonly used in this sailing are—

(1) When the *Course* between the two places and their *latitudes* are given	To find the difference of longitude.
(2) When the *latitudes* and *longitudes* of the two places are given	To find the Course and distance between them.

CASE I.

131. To find the **latitude** and **longitude in,** the **course** and **distance** from a known place being given, by Middle Latitude.

Examples.

Ex. 1. A ship from lat. 52° 6′ N., long. 35° 6′ W., sailed S.W. by W., 256 miles: required her latitude and longitude in.

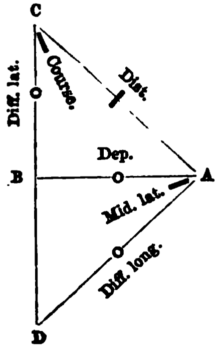
The figure used in this sailing is made up of *two* right-angled triangles, having one side (dep.) common to both.

One triangle is the figure used for *parallel* sailing, and the other is the figure used for *plane* sailing.

In the present case we have

[1] In the *Plane Sailing* figure or triangle A O B

Fig. 34.



Given {Course S. 56° 15′ W. dist. 256 miles.} to find {diff. lat. and dep.}

(See Case I, Plane Sailing, page 109.)

To find diff. lat.

$\frac{BC}{AC}$, **or** $\frac{\text{diff. lat.}}{\text{dist.}}$ **= cos. course.**

∴ log. diff. lat. = log. dist. + log. cos. co. — 10 (1).

(1)

Log. dist. 256 = 2·40824
Log. cos. course 56° 15′ = 9·74474

Log. diff. lat. = 2·15298
∴ Diff. lat. = 142·2 or 2° 22′.

Diff. lat.
6,0)14,2

Diff. lat. 2 22

To find dep.

$\frac{AB}{AC}$, **or** $\frac{\text{dep.}}{\text{dist.}}$ **= sin. course.**

∴ log. dep. = log. dist. + log. sin. co. — 10 (2)

(2)

Log. dist. 256 = 2·40824
Log. sin. course 56° 15′ = 9·91985

Log. dep. = 2·32809
∴ Dep. = 212·9.

Diff. lat. 2° 22′ S.
Lat. from 52 6 N.

Lat. in 49 44 N.

Sum 101 50

Mid. lat. 50 55

} Rule XXVI, p. 80, and Rule XXVII, page 82.

[2] In the *Parallel Sailing* figure or triangle A B D are given the dep. and middle lat. just found, whence

$\frac{AD}{AB}$, **or** $\frac{\text{diff. long.}}{\text{dep.}}$ **= sec. mid lat.**

∴ log. diff. long. = log. dep. + log. sec. mid. lat. — 10 (3).

Log. dep. = 2·32818
Log. sec. mid. lat. 50° 55′ = 10·20035

Log. diff. long. = 2·52853

∴ Diff. long. = 337·7.

D. Long.
6,0)33,8

5 38

Long. from 35° 6′ W.
D. long. 5 38 W.

Long. in 40 44 W.

} Rule XXIX page 84.

By Inspection.

RULE XLIX.

1°. *With the given* course *and* distance *enter the Traverse Table, and take out* true difference of latitude and departure (see Rule XL, page 112).

2°. *With* difference of latitude *and* latitude from, *find* latitude in (see Rule XXVI, page 80).

3°. *Get the* middle latitude, as directed, Rule XXVII, page 82.

4°. *With the middle latitude as* course, *look in the* difference of latitude *column for the* departure, *the corresponding* distance *at the top is the* difference of longitude.

5°. *With* difference of longitude *and* longitude from *get* longitude in, *as in* Rule XXIX, page 84.

NOTE.—When the *departure* to be looked for as *difference of latitude* at the middle latitude is beyond the limits of the Table, one-half, one-third, &c., must be used, and the resulting *difference of longitude* multiplied by the divisor, in order to get the whole *difference of longitude.*

Ex. (above). A ship from lat. 52° 6′ N., long. 35° 6′ W., sails S.W. by W., 256 miles: required her latitude and longitude in.

(1) Course S. 5 pts. W. } gives (in Table I) diff. lat. 142·2 and dep. 212·9 (see Rule
Dist. 256 miles } XL, page 112).

D. Lat.
6,0)14,2
2° 22′

Diff. lat. 2° 22′ S.
Lat. from 52 6 N.
Lat. in 49 44 N.
2)101 50
Mid. lat. 50 55

(2) Mid. lat. 51° (taken to nearest degree) as course, and half the dep. 106·4 (the whole dep. exceeding the limits of the table) in the *diff. lat.* column give in *dist.* column 169 miles, the half of the diff. of long. Then 169 × 2 = diff. long. 338 miles.

D. Long.
6,0)33,8
5 38

Diff. long. 5° 38′ W.
Long. from 35 6 W.
Long. in 40 44 W.

Explanation of Inspection.—The difference of latitude and departure is found as described in Rule XL, page 112. The latitude in is found by Rule XXVI, page 80; and thence the middle latitude, by adding the latitude from and latitude in together, and divided by 2 (see Rule XXVII, page 82). The departure exceeding the limits of the Tables, the half is taken. Then with *middle latitude* as a *course,* and *half the departure,* in *difference of latitude* column, half the difference of longitude is found in the *distance* column. This being doubled (as half the departure was taken) and divided by 60, gives the difference of longitude expressed in degrees and minutes. The ship is in *West* longitude, *sailing West,* add difference of longitude to longitude left to obtain longitude in (see Rule XXIX, page 84).

This Method by Inspection is the usual case at sea of Working the Day's Work.

Ex. 2. A ship from the Lizard, in lat. 49° 57′ N., sails between the South and West until diff. lat. is 126·7, and dep. 102·6: required the latitude come to, and difference of longitude.

6,0)12,6·7
2 6·7 or 2° 7′ S.
Lat. left 49 57 N.
Lat. in 47 50 N.
2)97 47
Mid. lat. 48 53

(See Rule XXVI, page 80, and Rule XXVII, page 82.)

By Inspection.

Then mid. lat. 48° 54′, say 49°, as a course, and dep. 102·3 (nearest), found in the lat. column, opposite to which, in the dist. column, is 156, nearest, the difference of longitude.

By Calculation.

Mid. lat. 48° 53′ sec. 0·182042
Dep. 102·6 log. 2·011147
Diff. long. 156·0 log. 2·193189

CASE II.

132. Given the **latitudes** and **longitudes** of **two places,** to find the **departure,** and thence the **course** and **distance** between them.

RULE L.

1°. *On the* left *hand of the page set down the* latitude *of the place* from, *underneath which put the* latitude *of the place* bound to, *or* worked for.

2°. *In the* middle of the page write down the latitude *of the place* from, *underneath which put the* latitude *of the place* bound to.

3°. *On the* right hand *of the page write down the* longitude *of the* place from, *underneath which put down the* longitude *of the* place bound to.

4°. *When the latitudes are* both *of the* same name *take the* less *from the* greater, *but when they are of* contrary names *take their* sum: *the result, in either case, multiplied by* 60 *will give the difference of latitude in miles* (Rule XXIV, page 78).

5°. Find the **middle latitude,** as follows:—

(a) *When the latitudes are* both *of the* **same** *name half their* **sum** *will give the* middle *latitude* (see Rule XXVII, page 82).

(b) *When the latitudes are of* **contrary** *names,* and very nearly equal, or very unequal, *half the* **greater** *latitude may be employed as the* middle latitude. *In an intermediate case we may combine the two* middle latitudes, *giving the* greater weight *to that which* corresponds *to the* greater *latitude.*

When the longitudes *of the two places are* both *of the* **same** *name take the* less *from the* greater, *but when they are of* **contrary** *names take their* **sum**: *the result in either case, multiplied by* 60 *will give the difference of longitude.*

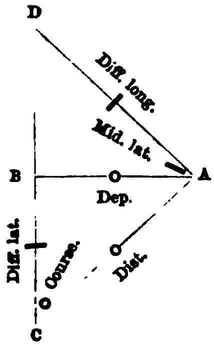
When the difference of longitude exceeds 180°, *take it from* 360°: *the remainder, multiplied by* 60, *will be the diff. long. in miles.*

EXAMPLE.

Find the Course and Distance between Tynemouth and the Naze of Norway.

Lat. Tynemouth	55° 1′ N.	....	55° 1′ N.	Long. Tynemouth	1°25′ W.
Lat. Naze of Norway	57 58 N.		57 58 N.	Long. Naze of Norway	7 2 E.
	2 57		112 59		8 27
	60				60
		Mid. lat.	56 29½		
D. lat.	177 N.			D. long.	507 E.

Fig. 35.



In the present case we have

1st. In the parallel sailing figure the *mid. lat.* and *diff. long.* given from which to find the *dep.*

2nd. In the plane sailing figure the *diff. lat.* and the *dep.* (just found) are given to determine the course and distance.

(1st) In triangle A D B.

By Parallel Sailing.

$$\text{Given}\left\{\begin{array}{l}\angle BAD = 56^\circ\ 29\tfrac{1}{2}' \\ \quad\text{the mid. lat.} \\ AD = 507 \\ \quad\text{the diff. long.}\end{array}\right\}\text{to find}\left\{\begin{array}{c}AB \\ \text{the} \\ \text{Dep.}\end{array}\right.$$

$\frac{AB}{AD}$, or $\frac{\text{dep.}}{\text{diff. long.}}$ = cos. mid. lat.

∴ dep. = diff. long. cos. mid. lat.

Log. diff. long. 507 = 2·70501
Log. cos. mid. lat. 56° 29½′ = 9·74199

Log. dep. = 2·44700

∴ Dep. = 279·9.

By Inspection.

With Mid. Lat. 56½° as Course, and one-third Diff. Long. 169 (the whole being too large for the table), the corresponding diff. lat. is 93·2, which is one-third the required departure; then 93·2 × 3 = 279·6 the dep.

NOTE.—The mid. lat. lying between two whole degrees the table is first entered with mid. lat. 56° as course, and one-third diff. long. 169 = (507 ÷ 3) in *dist.* column, which gives in *D. Lat.* column 94·5.

Next enter table with mid. lat. 57° as course and 169 in *dist.* column, then in the diff. lat. column is found 92·0; then (94 5 + 92·0) ÷ 2 = 93·2, one-third the required dep.

(2nd) In triangle A B C.

By Plane Sailing.

$$\text{Given}\left\{\begin{array}{l}AB = 279\cdot9 \\ \qquad\text{the dep.} \\ BC = 177 \\ \qquad\text{the diff. lat.}\end{array}\right.$$

$\frac{AB}{BC}$, or $\frac{\text{dep.}}{\text{diff. lat.}}$ = tan. co.

∴ Log. tang. course = log. dep. + 10 — log. diff. lat.

Log. dep 279·9 (+ 10) = 12·44700
Log. diff. lat. 177 = 2·24797

Log. tang. course = 10·19903

∴ Course = 57° 41½′
or N. 57° 41½′ E.

$\frac{AC}{BC}$, or $\frac{\text{dist.}}{\text{diff. lat.}}$ = sec. course.

∴ Dist. = diff. lat. sec. co.

Log. diff. lat. 177 = 2·24793
Log. sec. course = 0·27207

Log. dist. 2·52000

∴ Dist. = 331·2.

By Inspection.

With 93·2 (one-third dep.) in dep. column and one-third diff. lat. 59 in diff. lat. column the Course is found to be 57½°, and the dist. 110·5 multiplied by 3 gives the whole dist. 331·5 miles.

EXAMPLES FOR PRACTICE.

1. A ship from lat. 25° 35′ N., and long. 60° 0′ W., sails E.N.E., 296 miles: required the lat. and long. arrived at.

2. A ship from lat. 46° 14′ S., long. 178° 28′ E., sails S.E. ¾ E., dist. 278 miles: required the lat. and long. arrived at.

3. A ship from lat. 20° 29′ N., long. 179° 10′ W., sails W. by S. ½ S., 333 miles: required the lat. and long. arrived at.

4. Required the course and distance from A in lat. 48° 23′ N., long. 4° 29′ W., to B in lat. 44° 44′ N., long. 63° 36′ W.

5. Required the course and distance from a place in lat. 21° 18′ N., long. 157° 55′ W., to San Francisco in lat. 37° 48′ N., long. 122° 24′ W.

6. Required the course and distance from a place in lat. 58° 35′ N., and long. 56° 21′ W., to another place in lat. 60° 14′ N., and long. 5° 18′ E.

MERCATOR'S SAILING.

133. Mercator's Sailing, like Middle Latitude Sailing, relates to finding the difference of longitude a ship makes when sailing on any oblique rhumb, and is a perfectly general and rigorously true method, which the other is not.

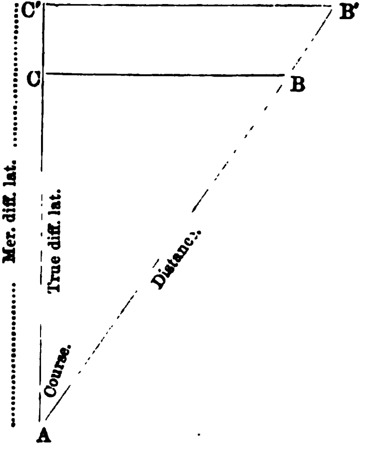
This sailing is derived from Mercator's projection of the globe upon a plane, or *flat* surface, in which the degrees of longitude are *every where equal;* the degrees of latitude *increase* from the Equator towards the Poles; and the meridians, parallels and rhumb lines (or course made by the ship) are *all* represented by straight lines (see *Def.*)

Mercator's Sailing is characterised by the use of the *Table of Meridional Parts*. With the assistance of this Table the rules of plane trigonometry suffice for the solution of all the problems.

In the triangle A C B let A be the course, A B the distance, A C the true difference of latitude, C B the departure; then corresponding to A C, the Table of Meridional Parts gives A C′, the meridional difference of latitude, and completing the right-angled triangle A C′B′, C′B will be the difference of longitude. In addition, then, to the three canons of *plane sailing* which can be deduced from the triangle A C B, the triangle A C′B′ gives the characteristic canon of *Mercator's Sailing* (since C′B′ = A C′ tang. A)

diff. long. = mer. diff. lat. × tang. course.

Fig. 36.



The two cases most commonly used in this sailing are—

(1) When the *latitudes and longitudes* of two places are given	To find the Course and Distance between them.
(2) When the *Course* between two places and their latitudes are given	To find the difference of longitude.

134. Given the **latitudes** and **longitudes** of two places, to find the **course** and **distance** between them.

RULE LI.

1°. *On the left hand of the page write down the latitude of the place* **from,** *underneath which put the latitude of the place* **bound to** (or worked for).

2°. *Write down, in the middle of the page, the corresponding meridional parts of the two latitudes.*

3°. *On the right hand of the page write down the longitude of the place* **from,** *underneath which put the longitude of the place* **bound to** (or worked for).

4°. *When the latitudes are both of the* **same** *name, take the less from the greater; but when they are of* **contrary** *names, take their* **sum:** the result, *in either case, multiplied by* 60 will give the true diff. lat. in miles (Rule XXIV, page 78).

5°. Having taken out the meridional parts of the two latitudes from Table III (Norie or Raper), *take their* **difference** *when the latitudes are of the* **same** *name; but their* **sum** *when the latitudes are of* **contrary** *names.* The result, in either case, *will be the meridional diff. lat.* (mer. diff. lat.) *in miles.* (See Rule XXV, page 79).

6°. *When the longitudes of the two places are both of the* **same** *name, take the* less *from the* greater; *but when they are of* **contrary** *names, take their* **sum:** the result, in either case, multiplied by 60 will give the diff. long. in **miles.** (See Rule XXVIII, page 82.)

Note.—When the diff. long. *exceeds* 180° take it from 360°, the remainder must be used as the diff. long. when turned into miles.

Note.—1st. Work with the triangle A C′ B′, which is formed by the side A C′, the *mer. diff. lat.*, and the side D A, the *diff. long.*, find ∠ A (the course), which is common to both triangles. 2nd. Having found the common ∠ C, work with triangle A C B, which is formed by A C, the *true* diff. lat., and A B, the *distance* required.

[1st.]
In triangle A C′ B′.
$$\text{Given}\left\{\begin{matrix}\text{mer. diff. lat.}\\ \text{diff. long.}\end{matrix}\right\}\text{ to find}\left\{\begin{matrix}\angle\ C\text{, the}\\ \text{course.}\end{matrix}\right.$$

[2nd.]
In triangle A C B.
$$\text{Given}\left\{\begin{matrix}\text{true diff. lat.}\\ \text{true course}\end{matrix}\right\}\text{ to find}\left\{\text{Distance}\right.$$

[1] $\frac{C'B'}{AC'}$ or $\frac{\text{diff. long.}}{\text{mer. diff. lat.}}$ = tang. course, ∴ log. tang. *course* — 10 = log. diff. long. — log. mer. diff. lat.

[2] $\frac{AB}{AC}$ or $\frac{\text{dist.}}{\text{true diff. lat.}}$ = sec. course, ∴ log. *dist.* = true diff. lat. + log. sec. course — 10.

Whence we have—

7°. To find the **course.**—*From the log. of diff. of longitude (increasing its index by* 10*), subtract the log. of meridional diff. of lat.: the remainder is the tangent of course, which take out of the tables, and place before it the letter of diff. of lat., and after it the letter of diff. of long.*

Note.—Be careful to remember that when the *sum* of the longitudes exceeds 180°, it must be taken from 360°, and the *course* must be *named the same* as the *longitude left.*

8°. To find the **distance.**—*To the secant of course (rejecting* 10 *from the index), add the log. of diff. of lat.: the sum is the log. of distance, the natural number corresponding to which find in the tables.*

By Inspection.

With the mer. diff. lat. as *diff. lat.*, and diff. long. as *dep.*, enter the Traverse Table and find the corresponding *course.* This will be the course required.

Again, with this course and the true diff. lat. as *diff. lat.* enter the Traverse Table and find the corresponding distance. This will be the distance required.

EXAMPLES.

Ex. 1. Required the course and distance from Tynemouth Light to the Naze of Norway.

Lat. Tynemouth	55° 1′ N.	Mer. parts	3970	Long. Tynemouth	1°25′ W.
Lat. Naze	57 58 N.	Mer. parts	4191	Long. Naze	7 2 E.
	2 57 60	Mer. diff. lat.	321		8 27 60
Diff. of Lat.	177 N.			Diff. of long.	507 E.

To find the Course.			*To find the Distance.*		
Diff. long. 507	Log. (+ 10)	12·705008	Course 57° 40′	Secant	0·271773
Mer. diff. lat. 321	Log.	2·506505	Diff. of lat. 177	Log.	2·247973
	Tang.	10·198503		Log.	2·519746
Course N. 57° 40′ E.			Distance 331.		

NOTE.—The course must be marked N. .... E., because the Naze of Norway (the place worked for) is to the *northward* and *eastward* of Tynemouth, the place *from*.

Ex. 2. Required the course and distance from A to B.

Lat. A	51°23′ N.	Mer. parts	3606	Long. A	9°29′ W.
Lat. B	48 23 N.	Mer. parts	3326	Long. B	4 29 W.
	3 0 60	Mer. diff. lat.	280		5 0 60
Diff. of lat.	180 S.			Diff. of long.	300 E.

Diff. long. 300	Log. (+ 10)	12·477121	Course 46° 58½′	Secant	0·166014
Mer. diff. lat. 280	Log.	2·447158	Diff. lat. 180	Log.	2·255273
	Tang.	10·029963		Log.	2·421287
Course S. 46° 58½′ E.			Distance 263·8		

Ex. 3. Required the course and distance from Cape Bajoli to Cape Sicie.

Lat. Cape Bajoli	40° 1′ N.	Mer. parts	2624	Long. Cape Bajoli	3°48′ E.
Lat. Cape Sicie	43 3 N.	Mer. parts	2867	Long. Cape Sicie	5 51 E.
	3 2 60	Mer. diff. lat.	243		2 3 60
Diff. of lat.	182 N.			Diff. of long.	123 E.

Diff. long. 123	Log. (+ 10)	12·089905	Course 26° 51′	Secant	0·049542
Mer. diff. lat. 243	Log.	2·385606	Diff. lat. 182	Log.	2·260071
	Tang.	9·704299		Log.	2·309613
Course N. 26° 51′ E.			Distance 204.		

Ex. 4. Required the course and distance from Cape Formosa to St. Helena

Lat. Cape Formosa	4°15′ N.	Mer. parts	255	Long. Cape Formosa	6°11′ E.
Lat. St. Helena	15 55 S.	Mer. parts	968	Long. St. Helena	5 45 W.
	20 10	Mer. diff. lat.	1223		11 56
Diff. of lat.	1210 S.			Diff. of long.	716 W.

Diff. long. 716	Log. (+ 10)	12·854913	Course 30° 21′	Secant	0·064012
Mer. diff. lat. 1223	Log.	3·087426	Diff. of lat. 1210	Log.	3·082785
	Tang.	9·767487		Log.	3·146797
Course S. 30° 21′ W.			Distance 1402.		

Ex. 5. Required the course and distance from Bahia to Fernando Po.

Lat. Bahia	13° 1′ S.	Mer. parts 788	Long. Bahia	38° 32′ W.
Lat. Fernando Po	3 48 N.	Mer. parts 228	Long. Fernando Po	8 43 E.
	16 49	Mer. diff. lat. 1016		47 15
Diff. of lat.	1009 N.		Diff. of long.	2835 E.

Diff. long. 2835	Log. (+ 10)	13·452553	Course 70° 17′	Secant	0·471895
Mer. diff. lat. 1016	Log.	3·006894	Diff. of lat. 1009	Log.	3·003891
	Tang.	10·445659		Log.	3·475786
Course N. 70° 17′ E.			Distance 2991.		

Ex. 6. Required the course and distance from A to B.

Lat. A	44° 44′ S.	Mer. parts 3007	Long. A	148° 39′ W.
Lat. B	55 55 N.	Mer. parts 4065	Long. B	44 44 E.
	100 39	Mer. diff. lat. 7072		193 23 E.
				360 0
Diff. of lat.	6039 N.			166 37 W.
			Diff. of long.	9997 W.

Diff. long. 9997	Log. (+ 10)	13·999870	Course 54° 43′ 0″	Secant	0·238358
Mer. diff. lat. 7072	Log.	3·849542	Parts for 26″		77
54° 43′	Tang.	10·150328	Diff. of lat. 6039	Log.	3·780965
		210	10457	Log.	4·019400
		446)11800(26			116
		892			416)2840(7
		2880			
		2676			

∴ Course N. 54° 43′ 26″ W., distance 10457 miles (nearly).

This question worked to the nearest minute of arc gives course N. 54° 43′ W., and distance 10455 miles.

Ex. 7. Required the course and distance from Cape East, New Zealand, to Cape Horn.

Lat. Cape East	37° 42′ S.	Mer. parts 2445	Long. Cape East	178° 40′ E.
Lat. Cape Horn	55 59 S.	Mer. parts 4072	Long. Cape Horn	67 16 W.
	18 17	Mer. diff. lat. 1627		245 56 W.
Diff. of lat.	1097 S.			360 0
				114 4
			Diff. of long.	6844 E.

Diff. long. 6844	Log. (+ 10)	13·835310	Course 76° 37′ 0″	Secant	0·635515
Mer. diff. lat. 1627	Log.	3·211388	Parts for 39″		345
76° 37′	Tang.	10·623922	Diff. of lat. 1097	Log.	3·040207
		558			3·676067
		935)36400(39			53
		2805			92)140(2
		8350	Distance 4743·2 nearly.		
		8415			
Course S. 76° 37′ 39″ E.					

EXAMPLES FOR PRACTICE.

Required the course and distance from A to B in each of the following examples:—

1.	A 38° 14′ N. B 39 51 N.	A 2° 7′ E. B 4 18 E.
2.	A 49 53 N. B 48 28 N.	A 6 19 W. B 5 3 W.
3.	A 64 30 N. B 60 40 N.	A 4 20 W. B 0 10 E.
4.	A 54 54 S. B 34 22 S.	A 60 28 W. B 18 24 E.
5.	A 45 15 N. B 47 10 N.	A 35 26 W. B 32 15 W.
6.	A 4 24 N. B 8 48 S.	A 7 46 W. B 13 8 E.
7.	A 40 0 S. B 8 57 N.	A 148 30 E. B 79 31 W.
8.	A 81 15 N. B 0 0	A 0 0 B 81 15 W.
9.	A 35° 14′ S. B 18 23 S.	A 75° 30′ E. B 12 2 E.
10.	A 41 10 S. B 53 19 N.	A 41 30 W. B 0 0
11.	A 6 11 N. B 6 0 S.	A 80 15 W. B 39 16 W.
12.	A 52 10 N. B 40 15 S.	A 176 9 E. B 179 29 W.
13.	A 35 51 S. B 38 52 N.	A 138 54 E. B 165 53 W.
14.	A 15 30 N. B 15 30 S.	A 176 34 E. B 176 34 W.
15.	A 22 22 S. B 33 33 N.	A 122 22 W. B 111 11 E.
16.	A 17 0 N. B 20 0 N.	A 180 0 E. B 161 0 E.

135. To find the **latitude** and **longitude in,** having given the **latitude from** and the **course** and **distance** between the two places.

By Calculation.

The general method of solution by meridional parts is from the formula

True diff. lat. = dist. × cos. course. ∴ log. *true diff. lat.* = log. dist. + log. cos. course − 10.	Diff. long. = mer. diff. lat. × tang. course. ∴ log. *diff. long.* = log. mer. diff. lat. + log. tang. course − 10.

EXAMPLES.

Ex. 1. A ship from lat. 55° 1′ N., long. 1° 25′ W., sails S.S.E. ½ E., 246 miles: required the lat. in and long. in.

Dist. 246	Log. 2·39094
Course 2½ pts.	Cos. 9·94543
Diff. lat. 217·0	Log. 2·33637

$$\begin{array}{r} 6{,}0)21{,}7 \\ \hline 3\ \ 37 \end{array}$$

Lat. left	55° 1′ N.	Rule XXVI, 1°, page 80.
D. lat.	3 37 S.	
Lat. in	51 24 N.	

Mer. parts	3970	Rule XXV, page 79.
Mer. parts	3607	
Mer. diff. lat.	363	

To find Diff. Long.

Mer. diff. lat. 363	Log. 2·55991
Course 2½ pts.	Tang. 9·72796
Diff. long. 194·0	Log. 2·28787

$$\begin{array}{r} 6{,}0)19{,}4 \\ \hline \text{D. long. } 3\ \ 14 \end{array}$$

Long. left	1° 25′ W.	Rule XXIX, page 84.
D. long.	3 14 E.	
Long. in	1 49 E.	

The ship being in 1° 25′, West of Greenwich, must evidently be in East longitude after having sailed 194 miles to the eastward (see Rule XXIX, page 84.

By Inspection.

RULE LII.

1°. *With given* course *and* distance *enter the Traverse Table and take out the corresponding* true difference of latitude, Rule XL, page 112, *from which and* latitude from *find* latitude in, *as in* Rule XXVI, page 80, *and then* meridional difference of latitude, *as in* Rule XXV, page 79.

2°. *At the given* course *look in the column of the* true difference of latitude *for the* meridional difference of latitude; *the corresponding* departure *will be the* difference of longitude, *from which and the* longitude from *find the* longitude in, *as in* Rule XXIX, page 84.

Entering Traverse Table I, with course 2½ points, and distance 246 miles, we obtain diff. lat. 217·0, or 3° 37′, which, being *subtracted* from lat. *left* 55° 1′ N. gives the lat. *in* 51° 24′ N. Taking out the *mer. parts* for 55° 1′ N. and 51° 24′ N., the *mer. diff. lat.* is found to be 363 (see above under Calculation).

Next, the course 2½ points and half mer. diff. lat. 181·5 (the number representing the mer. diff. lat. being greater than can be found in the table) in diff. lat. column, the nearest found in the table is 181·7, the corresponding departure is 97·1, which multiplied by 2 (having divided mer. diff. lat. by 2) gives diff. long. 194·2 miles, whence *diff. long.* is (194 ÷ 60) = 3° 14′ E., whence long. in is 1° 49′ E., as found by calculation above.

Ex. 2. A ship from lat. 42° 36′ S., long. 178° 43′ E., sails S. 53° E. until she arrives in lat. 45° 34′ S.: find diff. long. and long. in.

Lat. left	42° 36′ S.	Mer. parts	2830	Rule XXV, page 79.
Lat. in	45 34 S.	Mer. parts	3078	
		Mer. diff. lat.	248	

Given { Mer. diff. lat. 248, Course S. 53° E. } to find { Diff. long. }

Mer. diff. lat. 248	Log. 2·39445	Long. left	178° 43′ E.	See Rule XXIX, 1°, page 84.
Course 53°	Tang. 10·12289	D. long.	5 29 E.	
D. long. 329·1	Log. 2·51734	Exceeds 180°	184 12 E.	
		Subtract from	360 0	
6,0)32,9·1				
5° 29′		Long. in	175 48 W.	

By Inspection.

Entering Traverse Table II, with course 53°, and half mer. diff. lat. 124 (the whole mer. diff. lat. being too large for the tables) in diff. lat. column give in dep. column 164·5, which doubled (as mer. diff. lat. was divided by 2) gives 329′ the *diff. of long.*

Ex. 3. From lat. 50° 48′ N., and long. 1° 10′ W., sailed S. 41° E., 275 miles: required the lat. in and long. in.

In the Traverse Table at the distance 275, and *course* 41°, the corresponding *true diff. lat.* is 207·5, or 3° 27′·5, which being subtracted from 50° 48′ N., the *lat. in* is 47° 20′·5 N.; taking out the *mer. parts* for 50° 48′, and 47° 20′·5, the *mer. diff. lat.* is found to be 317, to *half* which as a *true diff. lat.*, and the course 14°, the *dep.* is 137·8, twice which is 275·6,—that is, the *diff. long.* is 4° 36′ E.: hence the long. in is 3° 26′ E.

EXAMPLES FOR PRACTICE.

For examples for practice in this problem take Examples 1, 2, and 3, given in Middle Latitude Sailing at page 130.

REMARKS ON MIDDLE LATITUDE AND MERCATOR'S SAILINGS.

136. "The difference of longitude found by middle latitude is true at the equator, and very nearly true for short distances in all latitudes, especially when the course is E. or W. In high latitudes, when the distance is great and the course oblique, the error becomes considerable: but the result may be made as accurate as we please by sub-dividing the distance run into small portions, and finding the difference of longitude for each portion separately. The difference of longitude deduced by middle latitude sailing is too small: an estimate of the error for places on the same side of the equator may be formed by the help of a few cases. Suppose the course 4 points or 45°, and the difference of latitude 10° or 600′; then if this difference of latitude is made good in any latitude below 30°, the error of the difference of longitude will not exceed 2′; if made good between the parallels of 40° and 50°, the error will be about 3′; and between 60° and 70° about 19′, or ⅓ of a degree. For smaller distances the errors will be much less, and for greater distances much greater, as they vary in much more rapid proportion than the distances. It has been observed before that when the course is large, the difference of longitude should be found by middle latitude in preference to Mercator's sailing; because, although the latter is mathematically correct in principle, yet a small error in the course may, when the course is large, produce a considerable error in the difference of longitude. The reason of this is easily shown. In middle latitude sailing we convert the *departure* into difference of longitude. The process increases the departure in a proportion which is less than 2 to 1 in all latitudes below 60°; and exceeds 3 to 1 in all latitudes beyond 70°. The error of the departure, increased in the same proportion, becomes thus the error of difference of longitude. Now when the course is nearly E. or W., the departure is nearly the same as the distance, and an error of some degrees in the course does not affect the departure sensibly; hence in this case the error of the difference of longitude depends on that of the distance alone. But in Mercator's sailing, on the other hand, we convert the *meridional difference of latitude* into difference of longitude, and the process when the course is large, converts a given meridional difference of latitude into a difference of longitude much greater than itself; and thus increases the error of the meridional difference of latitude, in the same proportion. Thus, for example, at the course 80°, the difference of longitude exceeds the meridional difference of latitude in the proportion of 6 to 1; at the course 85° this proportion is 11 to 1. Now, when the course is large, a slight change in it sensibly affects the difference of latitude, and also the meridional difference of latitude, which is deduced directly from it. In high latitudes the meridional parts vary rapidly, and the error of the difference of longitude is increased accordingly; hence the precept more especially demands attention in high latitudes."—*Raper's Practice of Navigation*, pp. 103-104.

THE DAY'S WORK.

137. This is the process of *finding the ship's place at* **Noon**—that is, its latitude and longitude, having given the latitude and longitude at noon preceding, or a departure taken since, the compass courses and distances run in the interval, the leeway (if any), variation and deviation (if any), direction and rate of current (if any), &c., &c.

RULE LIII.*

1°. *Correct each* course *in succession for* leeway, variation, *and the* deviation *due to the direction of the ship's head* (see Rules XXX to XXXVI, pages 94 to 106), *which arrange in the tabular form as in the example following.* Add *together the* hourly distances *sailed on each* course, *and insert the same in the Table, opposite the true course.*

NOTE.—Allow the leeway in points before expressing the course in degrees.

(a) If a ship has been lying-to, take the **middle** point *between the direction of her head when she* comes up to the wind *and when she* falls off *from it for the* course. *Allow to this course the* mean of the deviation upon the two directions of her head as the deviation, then correct for variation and leeway as usual.

Departure Course.—*When a departure has been taken, consider the* opposite to the bearing *as a* course, *which correct for* variation, and the **deviation due to the direction of the ship's head when the bearing was taken,** *and insert in the Table as an actual* course, *with the* distance *of the object as a* distance. *The* departure course *is generally put down in the Tables as the* first course.

As the ship leaves the land, the bearing (by compass) of some prominent object or known headland is taken, and its distance is generally estimated by the eye; this process is called "taking a departure." The latitude and longitude of the landmark are known; and thence, by supposing the ship to have sailed on a course the *opposite* to the bearing of the object, through the distance that object is off, we thus obtain, on commencing a voyage, a determinate starting point, from whence to reckon the subsequent courses and distances. Thus, supposing, for example, a ship leaving the Tyne observes Tynemouth Light dipping, and setting it, finds its bearing to be W. by N., distant (by estimation) 20 miles. Now in sailing from Tynemouth Light to the present position of the ship, she would have to sail in the *opposite* direction to the bearing of the light, viz., E. by S., 20 miles. At the end of the day, the Day's Work gives us a change of the ship's place as referred to the landmark, *and not the supposed position.* For methods of determining the distance, see *Raper's Practice of Navigation*, on Taking Departures, ch. IV, pp. 114-122.

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* Nearly the entire process of computing the Day's Work has already been given, and if the learner has thoroughly mastered the rules laid down in the preceding pages, he will find no difficulty in working the Day's Work without reference to them.

Current Course.—*The* set *of a current is to be corrected for* variation *only* (*being correct* magnetic), *and inserted in the Table as a* course; *the* drift *being taken as a* distance. *The* current course *is generally inserted in the Table as the* last course.

Having thus corrected all the courses

2°. *Take out of the Traverse Tables* (Table I or II, Raper or Norie) *the* difference of latitude *and* departure *to each* course *and* distance, (see Rule XL, page 112), *and proceed to find the* difference of latitude *and* departure *made good as directed in* Rule XLII, page 116, *Traverse Sailing.*

3°. *Find the* course *and* distance *made good* (see Rule XLI, page 114).

4°. **To find the latitude in** *by applying the* difference of latitude *to the* latitude from (see Rule XXVI, page 80).

(a) *When the lat. left and diff. lat.* are of the **same** name their **sum** will be the latitude in.

(b) When the lat. left and diff. lat. are of **contrary** names take the **difference,** and the remainder will be the lat. in, and of the same name as the greater.

If a departure has been taken, the difference of latitude is to be applied to latitude of the point of land; if otherwise, to yesterday's latitude.

To find the difference of longitude.—The difference of longitude is obtained from the departure made good either by Middle Latitude or Mercator's method; and when a ship has made a due East or West course, the diff. long. is found by Parallel Sailing.

Note.—When the course is less than 5 points or 56°, the difference of longitude may be found by either or both *Middle Latitude* or *Mercator's* method, but if the course exceeds 5 points the method of *Middle Latitude* should be used in preference to *Mercator's* (see *Remarks* in page 137).

5°. **To find the difference of longitude** *by Middle Latitude Sailing.*

(a) *Find the* middle latitude *as directed*, Rule XXVII, page 82.

(b) *Next at the page of Traverse Table on which the* degrees *(at top or bottom) correspond to* middle latitude, *find the* departure *in a* difference of latitude *column, then the corresponding* distance *is the* difference of longitude *of the same name as the* departure (see Rule XLIX, 4°, page 128).

Note.—If the departure exceeds 300 take half of it, and, having found the distance corresponding thereto, double it.

(c) **Or thus, by calculation:**—*To log. sec. of middle latitude* add *log. of dep.*, the sum *(rejecting* 10 *from the index) is the log. of diff. of long.* (see page 127).

When the latitude *left* and latitude *in* are of *contrary* names, that is, in low latitudes, no sensible error can arise from taking the departure itself as the difference of longitude.

6°. **To find the difference of longitude** *by Parallel Sailing.*

With the latitude as a course and the departure in a difference of latitude *column, then the corresponding* distance *is the* difference of longitude (see Rule XLIII, page 122).

7°. **To find the difference of longitude** *by Mercator's Sailing.*

(a) *Find meridional difference of latitude* (see Rule XXV, page 80).

(b) *Then with* course *and* meridional difference of latitude *(in a* latitude *column), find the corresponding* departure, *which is the* difference of longitude (see Rule LII, page 136).

(c) **To find the longitude in.**—*Under the long. left write the D. Long.*, *with the* same name *as the* Dep. *If long.* left *and* D. Long. *have the* **same** *name* (E. or W.) *take their* **sum** *for the* Long. in, *of the* same *name as* Long. left. Except *their sum* exceeds 180°, *in which case* subtract *it from* 360°, *and mark the* remainder W. *when long. left is* E., *but* E. *when long. left is* W. *If* long. left *and* D. Long. *have* **different** *names* (one E. and the other W.) *take their* **difference** *for the* long. in, *of the* **same** name *as the* greater (Rule XXIX, page 84).

When a departure has been taken the longitude left is that of the point of land; otherwise that of yesterday.

EXAMPLE I.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	S.S.E. ½ E.	4	2	East.	2	7° E.	A point of land in lat. 42° 12′ S., long. 42° 58′ W., bearing by compass E. by N. ½ N. dist. 21 miles. Ship's head S.S.E. ½ E.; deviation as per log.
2		4	3				
3		5					
4		5	2				
5		4					
6	N.N.E.	4	1	East.	2¼	9° E.	
7		3	8				
8		3	5				
9		3	2				
10	S.W. ½ W.	3	5	W.N.W.	1¾	7½° W.	
11		3	6				
12		4					
1		4	2				
2	N. ¼ E.	4	3	W.N.W.	2½	1° W.	Variation 20° W.
3		4	4				
4		4	5				
5	S.S.W.	6	2	West.	½	2½° W.	
6		6	4				
7		6	2				
8		6	5				A current set W.S.W. correct magnetic 26 miles from the time the departure was taken to the end of the day.
9	N. by W. ½ W.	6	2	West.	¾	10° W.	
10		5	7				
11		5	3				
12		5	4				

The Departure Course.

The opposite point to E. by N. ½ N. is W. by S. ½ S., and the ship's head being S.S.E. ½ E., the deviation is same as given in log. for S.S.E. ½ E., viz., 7° E.

W. by S. ½ S. = 6½ pts. R. of S.
or 73° 8′ R. of S.
Deviation 7° R. } 13 L.
Variation 20 L. }
True course 60 8 R. of S.
or S. 60° W., distance 21 miles.

This is inserted in the Traverse Table as 1st Course.

1st Course, S.S.E. ½ E.

		H.	K.
S.S.E. ½ E. =	2½ pts. L. of S.	1	4·2
Leeway	2 ,, R.	2	4·3
		3	5·0
	0½ ,, L. of S.	4	5·2
		5	4·0
	or 5° 38′ L. of S.		
Dev. 7° R. } Var. 20 L. }	13 L.		22·7
True course	18 38 L. of S.		

or S. 19° E., distance 22·7 miles.

The distance 22·7, is found by adding up the hourly distances sailed, until the course is altered at 6 o'clock. Insert this course and distance as 2nd course.

2nd Course, N.N.E.

The deviation for N.N.E. is 9° E.

		H.	K.
N.N.E. =	2 pts. R. of N.	6	4·1
Leeway	2¼ ,, L.	7	3·8
		8	3·5
	0¼ ,, L. of N.	9	3·2
	or N. 2° 49′ W. of N., L. of N.		14 6
Dev. 9° R. } Var. 20 L. }	11 L.		
True course	13 49 L. of N.		

or N. 14° W., distance 14·6 miles.

The distance, 14·6 is found by adding up the hourly distances from 6 o'clock until the course is changed at 10 o'clock.

3rd Course, S.W. ½ W.

The deviation for S.W. ½ W. is 7½° W.

		H.	K.
S.W. ½ W. =	4½ pts. R. of S.		
Leeway	1¾ ,, L.	10	3·5
		11	3·6
	2¾ ,, R. of S.	12	4·0
		1	4·2
	or 30° 56′ R. of S.		
Dev. 7° 30′ L. } Var. 20 0 L. }	27 30 L.		15·3
True course	3 26 R. of S.		

or S. 3° W., distance 15·3 miles.

Distance, 15′·3, is found by adding up hourly distances from 10 o'clock until 2.

4th Course, N. ½ E.

The deviation for N. ½ E. is 1° W.

		H.	K.
N. ¼ E. =	½ pt. R. of N.		
Leeway	2½ ,, R.	2	4·3
		3	4·4
	2¾ ,, R. of N.	4	4·5
	or 30° 56′ R. of N.		13·2
Dev. 1° L. } Var. 20 L. }	21 0 L.		
True course	9 56 R. of N.		

or N. 10° E., distance 13·2 miles.

5th Course, S.S.W.

The deviation for S.S.W. is 2½° W.

		H.	K.
S.S.W. =	2 pts. R. of S.		
Leeway	½ ,, L.	5	6·2
		6	6·4
	1½ ,, R. of S.	7	6·2
		8	6·5
	or 16° 53′ R. of S.		
Dev. 2° 30′ L. } Var. 20 0 L. }	22 30 L.		25·3
True course	5 37 L. of S.		

or S. 6° E., distance 25·3 miles.

6th Course, N. by W. ½ W.

The dev. for N. by W. ½ W. is 10° W.

		H.	K.
N. by W. ½ W. =	1¼ L. of N.	9	6·2
	½ R.	10	5·7
		11	5·3
	¾ L. of N.	12	5·4
	or 8° 26′ L. of N.		·22·6
Dev. 10° L. } Var. 20 L. }	30 0 L.		
True course	38 26 L. of N.		

or N. 38° W., distance 22′·6.

Current Course, W.S.W.

W.S.W. = 6 pts. R. of S.
or 67° 30′ R. of S.
Deviation 20 0 L.
47 30 R. of S.
or S. 48° W., distance 26′.

The corrected courses are written down to the nearest degree, and the work will stand as follows:—

Courses.	Dist.	N.	S.	E.	W.
S. 60° W.	21		10·5		18·2
S. 19 E.	22·7		21·5	7·4	
N. 14 W.	14·6	14·2			3·5
S. 3 W.	15·3		15·3		0·8
N. 10 E.	13·2	13·0		2·3	
S. 6 E.	25·3		25·2	2·6	
N. 38 W.	22·6	17·8			13·9
S. 48 W.	26		17·4		19·3
		45·0	89·9	12·3	55·7
			45·0		12·3
			44·9		43·4

Difference latitude 44·9 } give in Table II { Course S. 44° W.* } Rule XLI,
Departure 43·4 } { Distance 62½ miles. } page 114.

Latitude left 42° 12′ S.
Diff. latitude 45 S.
Latitude in 42 57 S.
Sum 2)85 9
Middle lat. 42 34
} Rules XXVI and XXVII, pages 80 and 82.

Meridional parts 2798
Meridional parts 2859
Mer. diff. lat. 61
} Rule XXV, page 79.

Course S. 44° W. } give in Table II { Difference of longitude 59·0
Mer. diff. lat. 61 } { (in departure column).

Mid. latitude 42½° } give in Table II { Difference of longitude 59′
Dep. 43·4 (as d. lat.) } { (in distance column).

Longitude left 42° 58′ W.
Diff. longitude 0 59 W.
Longitude in 43 57 W.
} Rule XXIX, page 84.

Previous to opening the Traverse Table to take out the difference of latitude and departure to each course and distance in the above table, fill up the columns not wanted: thus, in the first course, S. 60° W. the S. and W. will be wanted, and the N. and E. will not be wanted; fill up these last two columns by drawing a dash under N. and E. Proceed in the same manner with the other courses.

2. *To find the difference of latitude and departure* to each course and distance by the Traverse Table.

Enter Traverse Table, and take out the difference of latitude and departure corresponding to 60° and distance 21′. Insert them in the columns S. and W.

The second course is S. 19° E., and the distance 22′·7. Then, 19 degrees and distance 227 (omittting the decimal point) give difference of latitude 214·6, departure 73·9; now dropping the tenths in each, namely, the 6 and the 9, and shifting the decimal point one place to the left, we have difference of latitude 21·5, departure 7·4, which insert in columns S. and E., the course being marked S. and E.

The third course is N. 14° W., and distance 14·6. Look for 14 degrees and distance 14·6, which give difference of latitude 141·7, departure 35·3; now dropping the tenths, the 7 and the 3, and increasing the preceding figure by 1, in the first case, as the tenths exceed 5 we have, by removing the decimal point one figure to the left, the difference of latitude 14·2, and departure 3·5.

Proceed in this way with the remaining courses.

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* The course being less than 56°, the difference of longitude may be found both by middle latitude and Mercator's method.

Next we find the sum of the four columns, when it appears the ship has sailed 45·0 N., and 89·9 S.; therefore, upon the whole, the difference of latitude is 44·9 S. The sum of the eastings is 12·3, of the westings 55·7, and the departure made good is 43·4 W.

3. *To find the Course and Distance made good.*—The difference of latitude is 44·9 and departure 43·4 found to correspond in their columns, give course S. 44° W., distance 62½ miles (see Rule XLI, page 114).

4. We next apply the difference of latitude, 45′ S. (44·9), to the latitude left, 42° 12′ S., (the latitude of point of land), taking the *sum*, as they are of the same name, and the latitude 42° 57′ S., takes the name of either (Rule XXVI, page 80).

5. *To find the Difference of Longitude.*—Take out the meridional parts for latitude left, 42° 12′, and also for latitude in, 42° 57′, and take the less from the greater, as the latitudes are of one name. The remainder is meridional difference of latitude (XXV, page 79).

Or, find middle latitude by adding together latitude left and latitude in, and divide the sum by 2; the quotient is the middle latitude (Rule XXVII, page 82).

Then the course 44°, in Table II, and meridional difference of latitude 61′, found in difference of latitude column, gives in departure column 59′, or difference of longitude 59′ (Rule LII, 2°, page 136).

Or, the middle latitude 42½° in Table II, and departure 43·4 in difference of latitude column, gives in distance column 59′, the difference of longitude (Rule XLIX, 4°, page 128).

Thus:—Mid. lat. 42° and dep. 43′·4 give in dist. column 58½
and „ 43 „ 43·4 „ 59½

2)118

Diff. long. 59

The difference of longitude 59′ W. (that found by Mercator's sailing), added to longitude left 42° 58′ W., gives longitude in 43° 57′ W. (Rule XXIX, page 84).

EXAMPLE II.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	S. by W.	4	1	W. by S.	2¼	0°	A point of land in lat. 62° 18′ N., long. 85° 17′ E., bearing by compass N. by E. ½ E., 16 miles. Ship's head S. by W. Deviation as per log.
2		3	9				
3		4	0				
4		4	0				
5	S.W. ¾ W.	3	5	S. by E.	3½	8° W.	
6		3	4				
7		3	1				
8		3	0				
9	E. ¾ S.	5	4	S. by E.	1¾	15° E.	
10		5	6				
11		5	4				
12		5	6				
1	W.N.W.	4	4	North.	3	18½° W.	
2		4	4				Variation 42° E.
3		4	2				
4		5	0				
5	N.W. ½ N.	9	6	S. by W.	0	16½° W.	
6		10	2				
7		11	4				
8		11	8				
9	E. ¾ N.	3	4	N. by E.	3¼	19¾° E.	
10		3	2				A current set the ship W.S.W. (correct magnetic), 23 miles.
11		3	0				
12		2	4				

W. N. E. S. W. N.

The Departure Course.

The opposite point to N. by E. ¼ E. is S. by W. ¼ W., and the ship's head being S. by W., the deviation is the same as given in the log. for S. by W.

S. by W. ¼ W. = 1¼ pts. R. of S.
or 14° 4' R. of S.
Var. 42° R. } 42 0 R.
Dev. 0 }
True course 56 0 R. of S.
or S. 56° W., distance 16 miles.

This is inserted in the Traverse Table as 1st Course.

1st Course, S. by W.

The deviation for S. by W. is 0.

S. by W. = 1 pt. R. of S.
Leeway 2¼ " L.
1¼ " L. of S.
or 14° 4' L. of S.
Dev. 0 } 42 0 R.
Var. 42° R. }
True Course 28 0 R. of S.
or S. 28° W., distance 16'.

H.	K.
1	4·1
2	3·9
3	4
4	4
	16

The distance 16' is found by adding up the hourly distances until the course is changed at 5 o'clock. Insert this course and distance in Traverse Table as the 2nd course.

2nd Course, S.W. ¾ W.

The deviation for S.W. ¾ W. is 8° W.

S.W. ¾ W. = 4¾ pts. R. of S.
Leeway 3½ " R.
Sum exc. 8 pts. 8¼ " R. of S.
Subtract from 16
7¾ " L. of N.
or 87° 11' L. of N.
Dev. 8° L. } 34 0 R.
Var. 42 R. }
True Course 53 0 L. of N.
or N. 53° W., distance 13'.

H.	K.
5	3·5
6	3·4
7	3·1
8	3
	13

The distance is obtained by adding up the hourly distances sailed from 5 o'clock until the course is changed at 9 o'clock.

3rd Course, E. ¾ S.

The deviation for E. ¾ S. is 15° E.

E. ¾ S. = 7¼ pts. L. of S.
Leeway 1¾ " L.
Sum exc. 8 pts. 9 " L. of S.
Subtract from 16
7 " R. of N.
or 79° R. of N.
Dev. 15° R. } 57 R. of N.
Var. 42 R. }
Sum exc. 90° 136 R. of N.
Subtract from 180
True Course 44 L. of S.
or S. 44° E., distance 22'.

H.	K.
9	5·4
10	5·6
11	5·4
12	5·6
	22·0

Hourly distances sailed from 9 o'clock until course is changed at 1 o'clock being added up, give the distance to enter in the Traverse Table.

4th Course, W.N.W.

The deviation for W.N.W. is 18½° W.

W.N.W. = 6 pts. L. of N.
Leeway 3 " L.
Sum exc. 8 pts. 9 " L. of N.
Subtract from 16
7 R. of S.
or 78° 45' R. of S.
Dev. 18° 30' L. } 23 30 R.
Var. 42 R. }
Sum exc. 90° 102 R. of S.
Subtract from 180
True Course 78 L. of N.
or N. 78° W., distance 18'.

H.	K.
1	4·4
2	4·4
3	4·2
4	5
	18·0

The distance is found by adding up hourly distances sailed from 1 o'clock until the course is changed at 5 o'clock.

5th Course, N.W. ½ N.

The deviation for N.W. ½ N. is 16½° W.

N.W. ½ N. = 3½ pts. L. of N.
Leeway 0
3½ " L. of N.
or 39° 22' L. of N.
Dev. 16° 30' L. } 25 30 R.
Var. 42 R. }
True Course 13 52 L. of N.
or N. 14° W., distance 43'.

H.	K.
5	9·6
6	10·2
7	11·4
8	11·8
	43·0

Add up hourly distances sailed from 5 o'clock until course is changed at 9 o'clock.

6th Course, E. ¾ N.

The deviation for E. ¾ N. is 19¾° E.

			H.	K.
E. ¾ N. =	7¼ pts.	R. of N.		
Leeway	3¼ „	R.	9	3·4
			10	3·2
Sum exc. 8 pts.	10½ „	R. of N.	11	3·0
Subtract from	16		12	2·4
	5½ „	L. of S.		12·0

or 61°53′ L. of S.

Dev. 19°45′ R. Var. 42	61 45	R.
True Course	0 8	L. of S.

or South, distance 12′.

Current Course, W.S.W.

W.S.W. = 6 pts. R. of S.
or 67°30′ R. of S.

Variation	42 0	R.
Sum exc. 90°	109 30	R. of S.
Subtract from	180	
True course	70 30	L. of N.

or N. 71° W., distance 23′.

The corrected courses are written down to the nearest degree, and the work will stand as follows:—

Courses.	Dist.	N.	S.	E.	W.
S. 56° W.	16		8·9		13·3
S. 28 W.	16		14·1		7·5
N. 53 W.	13	7·8			10·4
S. 44 E.	22		15·8	15·3	
N. 78 W.	18	3·7			17·6
N. 14 W.	43	41·7			10·4
South	12		12·0		
N. 71 W.	23	7·5			21·7
		60·7	50·8	15·3	80·9
		50·8			15·3
		9·9			65·6

Course N. 81½° W., distance 66½ miles.

Diff. lat. 9′·9 and dep. 65′·6 being found to correspond in their columns, give course N. 81½° W., distance 66½ miles. Course exceeds 56°, diff. long. must be found by middle latitude sailing.

Lat. left	62°18′	N.
Diff. lat.	10	N.
Lat. in	62 28	N.
Sum	124 46	
Mid. lat.	62 23	

See Rules XXVI and XXVII, pp. 80 & 82.

The mid. lat. is high and between two whole degrees, therefore we proceed thus:—

Mid. lat. 62° as course (in Table II), and dep. 65·7 (nearest to 65·6) as diff. lat., give in dist. column 140; and mid. lat. 63° and dep. 65·8 (nearest to 65′·6) as diff. lat., give in dist. column 145: whence it is evident that for 1° (or 60′) of mid. lat., the diff. long. increases 5′: we next make the proportion

60′ : 23′ :: 5 : *x*
5
6,0)11,5
2 nearly, the correction for 23′.

Mid. lat. 62° gives D. long.	140
Correction for 23′	2
∴ Mid. lat. 62° 23′ gives D. long.	142

By Calculation.

Mid. lat. 62° 23′	sec.	0·333900
Dep. 65′·6	log.	1·816904
Diff. long. 141′·5	log.	2·150804

or 2° 21′5′.

Long. left	85°17′	E.
Diff. long.	2 22	W.
Long. in	82 55	E.

Rule XXIX, page 84.

EXAMPLE III.

H	Courses.	K	$\frac{1}{10}$	Winds.	Leeway pts	Deviation.	Remarks, &c.
1	E. by S.	10	6	S. by E.	¼	19° E.	A point of land in lat. 47° 44′ S., long. 179° 7′ E., bearing by compass N. b W. ½ W. dist. 11 miles. Ship's head E. by S. Dev. as per log.
2		11	4				
3		11	6				
4		11	4				
5		12					
6	E. ¾ S.	12		S.by E.½E.	½	20° E.	
7		12	3				
8		12	4				
9		12					
10		12	3				
11	E.S.E.	13	4	South.	¾	18° E.	
12		13	4				
1		13	6				Variation 14° E.
2		14	3				
3		14	3				
4	N.E. by E.	13	8	N. by W.	½	19° E.	
5		13	8				
6		13	5				
7		13	5				
8		13	4				
9	S.E. ¼ E.	12	5	SSW ½ W	¾	15° E.	A current set the ship N. W. by N. correct magnetic 13 mls. from the time the departure was taken to the end of the day.
10		12	5				
11	N. by E.	2	4	E.N.E.	5¾	2° E.	
12		2	6				

W. N. E. S. W. N.

Departure Course.

The opposite point to bearing N. by W. ½ W. is S. by E. ½ E.

S. by E. ½ E. = 1½ pts. L. of S.
or 16° 53′ L. of S.
Dev. 19° R.
Var. 14 R. 33 0 R.
16 7 R. of S.
or S. 16° W., distance 11′.

1st Course, E. by S., dev. 19° E.
E. by S. = 7 pts. L. of S.
Leeway = ¼ „ L.
7¼ „ L. of S.
or 81° 34′ L. of S.
Dev. 19° R.
Var. 14 R. 33 0 R.
True course 48 34 L. of S.
or S. 49° E., distance 57′.

2nd Course, E. ¾ S., dev. 20° E.
E. ¾ S. = 7¼ pts. L. of S.
Leeway = ½ „ L.
7¾ „ L. of S.
or 87° 11′ L. of S.
Dev. 20° R.
Var. 14 R. 34 0 R.
53 11 L. of S.
or S. 53° E., distance 61′.

3rd Course, E.S.E., dev. 18° E.
E.S.E. = 6 pts. L. of S.
Leeway ¾ „ L.
6¾ „ L. of S.
or 75° 56′ L. of S.
Dev. 18° R.
Var. 14 R. 32 0 R.
43 56 L. of S.
or S. 44° E., distance 69′.

4th Course, N.E. by E., dev. 19° E.
N.E. by E. = 5 pts. R. of N.
Leeway = ½ „ R.
5½ „ R. of N.
or 61° 53′ R. of N.
Dev. 19° R.
Var. 14 R. 33 0 R.
Sum exc. 90° 94 53 R. of N.
Subt. from 180 0
True course 85 7 L. of S.
or S. 85° E., distance 68′·0.

5th Course, S.E. ¼ E., dev. 15° E.
S.E. ¼ E. = 4¼ pts. L. of S.
Leeway = ¾ „ L.
5 „ L. of S.
or 56° 15′ L. of S.
Dev. 15° R.
Var. 14 R. 29 0 R.
True course 27 15 L. of S.
or S. 27° E., distance 25′.

6th Course, N. by E., dev. 2° E.
N. by E. = 1 pt. R. of N.
Leeway = 5¾ „ L.
4¾ „ L. of N.
or 53° 26′ L. of N.
Dev. 2° R.
Var. 14 R. 16 0 R.
37 26 L. of N.
or N. 37° W., distance 5′.

Current Course.

N.W. by N. = 3 pts. L. of N.
or 33° 45′ L. of N.
Var. 14 0 R.
19 45 L. of N.
or N. 20° W., distance 13′.

Courses.	Dist.	N.	S.	E.	W.
S. 16° W. ..	11		10·6		3·0
S. 49° E. ..	57		37·4	43·0	
S. 53° E. ..	61		36·7	48·7	
S. 44° E. ..	69		49·6	47·9	
S. 85° E. ..	68		5·9	67·7	
S. 27° E. ..	25		22·3	11·3	
N. 37° W. ..	5	4·0			3·0
N. 20° W. ..	13	12·2			4·4
		16·2	162·5	218·6	10·4
			16·2	10·4	
			146·3	208·2	

Diff. lat. 145·7 and dep. 208·1, found to correspond in the columns, give course S. 55° E., and distance 254 miles (see Rule XLI, page 114).

Lat. left, 47° 44′ S.
Diff. lat. 2 26 S.
Lat. in 50 10 S.
Sum 2)97 54
Mid. lat. 48 57

Rules XXVI and XXVII, pp. 80 and 82.

Mid. lat. 49° as course in Table II, and half of the dep. 104·1 (the whole dep. being too large a number to be found in the Table) gives in distance column 159 which multiplied by 2 (as only half the dep. was used in entering the Table) gives diff. long. 318 miles.

Mid. lat. 48° 57′ sec. 0·182621
Dep. 208·2 log. 2·318481
D. long. 317·0 log. 2 501102
or 5° 17′·0

Long. left 179° 7′ E.
D. Long. 317′ 5 17 E.
Sum exc. 180° 184 24 E.
Subt. from 360 0
Long. in 175 36 W.

Rule XXIX, page 84.

Note.—Use diff. long. 5° 17′ as found by Calculation in preference to that found by Inspection.

W. N. E. S. W. N.

Departure Course.
Opposite to bearing E. by S. ½ S.
6½ pts. L. of S.
or 73° 8′ L. of S.
Dev. 17°45′ R. } 3 30 L.
Var. 21 15 L. }
76 38 L. of S.
or S. 77° E., distance 15′.

1st Course, E. by N.
7 pts. R. of N.
Leeway ¼ „ L.
6¾ „ R. of N.
or 75°56′ R. of N.
Dev. 17°45′ R. } 3 30 L.
Var. 21 15 L. }
72 26 R. of N.
or N. 72° E., distance 49′.

2nd Course, E.S.E.
6 pts. L. of S.
Leeway ½ „ L.
6½ „ L. of S.
or 73° 8′ L. of S.
Dev. 13°30′ R. } 7 45 L.
Var. 21 15 L. }
80 53 L. of S.
or S. 81° E., distance 42′.

3rd Course, N.E. by E.
5 pts. R. of N.
Leeway 1 „ L.
4 „ R. of N.
or 45° R. of N.
Dev. 17°15′ R. } 4 L.
Var. 21 15 L. }
41 R. of N.
or N. 41° E., distance 33′.

4th Course, S.S.E.
2 pts. L. of S.
Leeway 1¼ „ R.
¾ „ L. of S.
or 8°26′ L. of S.
Dev. 5°30′ R. } 15 45 L.
Var. 21 15 L. }
24 11 L. of S.
or S. 24° E., distance 29′.

5th Course, S.E. by S.
3 pts. L. of S.
Leeway 2 „ R.
1 „ L. of S.
or 11°15′ L. of S.
Dev. 8°30′ R. } 12 45 L.
Var. 21 15 L. }
24 0 L. of S.
or S. 24° E., distance 22′.

6th Course, E.S.E.
6 pts. L. of S.
Leeway 2¼ „ R.
3¾ „ L. of S.
or 42°11′ L. of S.
Dev. 13°30′ R. } 7 45 L.
Var. 21 15 L. }
49 56 L. of S.
or S. 50° E., distance 19′.

Current Course, S.S.W. ½ W.
2½ pts. R. of S.
or 28° 7′ R. of S.
Var. 21 15 L.
6 52 R. of S.
or S. 7° W., distance 18′.

EXAMPLE IV.

H	Courses.	K	$\frac{1}{10}$	Winds.	Leeway	Deviation.	Remarks, &c.
					pts		
1	E. by N.	12	4	S.E. by S.	¼	17¾° E.	A point, Tynemouth in lat. 55° 1′ N., long. 1° 25′ W., bearing by compass W. b N. ½ N. dist. 15 miles. Ship's head E. by N. Dev. as per log.
2		12	2				
3		12	2				
4		12	2				
5	E.S.E.	10	6	South.	½	13½° E.	
6		10	5				
7		10	4				
8		10	5				
9	N.E. by E.	8	2	S.E. by E.	1	17¼° E.	
10		8	3				
11		8	3				
12		8	2				
1	S.S.E.	7	4	East.	1¼	5½° E.	Variation 21¼° W.
2		7	2				
3		7	2				
4		7	2				
5	S.E. by S.	5	8	E. by N.	2	8½° E.	
6		5	6				
7		5	4				
8		5	2				A current set the ship S.S.W. ½ W. correct magnetic 18 mls. from the time the departure was taken to the end of the day.
9	E.S.E.	5	4	N.E.	2¼	13½° E.	
10		4	6				
11		4	5				
12		4	5				

Courses.	Dist.	N.	S.	E.	W.
S. 77° E. ..	15		3·4	14·6	
N. 72 E. ..	49	15·1		46·6	
S. 81 E. ..	42		6·6	41·5	
N. 41 E. ..	33	24·9		21·6	
S. 24 E. ..	29		26·5	11·8	
S. 24 E. ..	22		20·1	8·9	
S. 50 E. ..	19		12·2	14·6	
S. 7 W. ..	18		17·9		2·2
		40·0	86·7	159·6	2·2
			40·0	2·2	
			46·7	157·4	

Diff. lat. 46′·7 } give in Table II { Course S. 73½° E.
Departure 157·4 } { Dist. 164½′

Lat. left 55° 1′ N.
Diff. lat. 47 S.
Lat. in 54 14 N.
2)109 15
Mid. lat. 54 37
} Rules XXVI and XXVII, pp. 80 and 82.

To find D. long.

(1) *By Calculation.*

Lat. 54° 37′ sec. 0·237288
Dep. 157′·4 log. 2·197005
D. long. 271·8 log. 2·434293

Mid. lat. 54° and dep. 157·5 in diff. lat. column (the nearest in Table to 157·4), gives in dist. column 268 for diff. long.; and mid. lat. 55° and dep. 157′·7 in diff. lat. column give in dist. column diff. long. 275; whence it is evident that for 1° change of mid. lat. we have (275 — 268) = 7′ change in diff. long., thus:—60 : 37 :: 7 : 4·3.

Mid. lat. 54°, dep. 157 give D. long. 268
Correction for 37′ + 4·3
∴ Mid. lat. 54°37′, dep. 157·4 give 272·3

Long left 1°25′ W.
D. long. 272′ or 4 32 E.
Long. in 3 7 E.
} Rule 29. page 81.

EXAMPLE V.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	N.E. ½ E.	6		N.N.W.	2¼	16¼° E.	A point of land in lat. 47° 35′ S., long. 179° 26′ E., bearing by compass S.E. ¾ E., dist. 14 miles. Ship's head N.E. ½ E. Dev. as per log.
2		6					
3		6	6				
4		6	4				
5	N.E. by E. ½ E.	5	7	S.E. ½ E.	2¼	17¾° E.	
6		5	8				
7		6	3				
8		6	2				
9	S.E. ¾ E.	12		N.E. by N.	0	11° E.	
10		12	4				
11		12					
12		11	6				Variation 25° E.
1	South.	4	6	E.S.E.	2	2¼° W.	
2		4	6				
3		4	6				
4		5	2				
5	N.W. b W. ½ W.	4	4	S.W. ½ W.	1¾	18½° W.	
6		4	5				A current set the ship N.E. by E. ¾ E., correct magnetic, 36 miles, from the time the departure was taken to the end of the day.
7		4	5				
8		4	6				
9	N.W. ½ W.	12	6	S.W. b W. ½ W.	¼	18° W.	
10		12	5				
11		12	4				
12		12	5				

Courses.	Dist.	N.	S.	E.	W.
N. 12° W.	14	13·7			2·9
S. 63 E.	25		11·3	22·3	
N. 79 E.	24	4·6		23·6	
S. 17 E.	48		45·9	14·0	
S. 45 W.	19		13·4		13·4
N. 36 W.	18	14·6			10·6
N. 41 W.	50	37·7			32·8
East	36			36·0	
		70·6 70·6	70·6	95·9 59·7	59·7
				36·2	

Having filled up the Traverse Table, the sum of the Northings and Southings are equal, consequently the latitude remains unaltered, or, the ship, after sailing the foregoing courses and distances, has returned to the same parallel. Altogether, the vessel has sailed 95′·9 towards the east on four courses, while she has made 59′·7 Westing on the other four, leaving 36′·2 of progress towards the East; hence

The Course is East, distance 36′·2 (see Rule XLII, 6° (b), page 117).

To find the Latitude and Longitude in.

The ship not having altered her latitude, the latitude arrived at is the same as the latitude left, viz., 47° 35′ S., and consequently the diff. of long. made good is to be found by Parallel Sailing, Rule XLIV, page 122, thus:—

Lat 47½° (as course) and Dep. (in diff. lat. column) } give in Table II { Diff. long. 53½′. (in distance column).

By Calculation (page 122).

Lat. 47° 35′	sec.	0·171007
Dep. 36′·2	log.	1·558709
Diff. long. 53·7	log.	1·729716

Long. left	179° 26′	E.
Diff. long.	+ 53·5	E.
Long. in	180 19·5	E.
Subtract from	360 0	
Long. in	179 40·5	W.

Rule XXIX, page 84.

EXAMPLES FOR PRACTICE.

EXAMPLE I.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
1	S.E. by S.	12	5	E. by N.	pts. ¼	3° E.	A point of land in lat. 35° 15′ N., long. 75° 30′ W., bearing by compass W. by N., dist. 19 miles. Ship's head S.E. by S.; deviation as per log.
2		12	5				
3		12	6				
4		12	4				
5	East.	9	8	N.N.E.	1	23° E.	
6		9	4				
7		9	4				
8		9	4				
9	N.E.	10	4	N.N.W.	¾	17° E.	
10		10	6				
11		10	4				
12		10	6				
1	North.	11		W.N.W.	¾	4° E.	Variation 15° W.
2		10	4				
3		10	2				
4		10	4				
5	N.N.E.	11		East.	½	13° E.	
6		10	4				
7		10	4				
8		10	2				A current set N.E. by E. correct magnetic 52 miles from the time the departure was taken to the end of the day.
9	E.N.E.	9	5	North.	1	18½° E.	
10		8	8				
11		9	4				
12		9	3				

EXAMPLE II.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
1	East.	9	4	S.S.E.	pts. ¾	16° E.	A point, Flambro' Head, lat. 54° 7′ N., long. 0° 5′ W., bearing by compass N.W. *b* W. dist. 17 miles. Ship's head E.S.E. Deviation 13° E.
2		9	6				
3		9					
4	S.E. by E.	10	4	S. by W.	½	12° E.	
5		10	2				
6		10	4				
7	E. ½ S.	6	7	S. by E. ½ E.	1¼	15° E.	
8		6	6				
9		6	7				
10	S. by W.	5		S.E. by E.	2	0°	
11		4	8				
12		4	6				
1		4	6				Variation 25° W.
2	South.	4	4	E.S.E.	2½	2° E.	
3		4	4				
4		4	2				
5	S.E. by S.	3	5	E. by N.	2¾	8° E.	
6		3	5				
7		3					A current set (correct magnetic) N.N.E., 6 miles, from the time the departure was taken to the end of the day.
8	E.N.E.	3		S.E.	3¼	18° E.	
9		3					
10		3					
11		3					
12		3					

EXAMPLE III.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	N.N.E.	9	5	East.	½	8° E.	A point of land in lat. 43° 47′ N., long. 7° 51′ W., bearing by compass S.W. by S., dist. 13 miles. Ship's head N.N.E. Deviation as per log.
2		9	5				
3		9	6				
4		9	4				
5	E.N.E.	3	6	S.E.	2¾	15¼° E.	
6		4	4				
7		5					
8		5					
9	E.S.E.	6		South.	2	13½° E.	
10		7					
11		6	4				
12		5	6				
1	W. by N. ½ N.	6		S.W. ½ S.	1½	15¾° W.	Variation 25° W.
2		5	6				
3		5	4				
4		6					
5	S.S.E.	5	6	S.W.	½	5½° E.	
6		6	2				
7		6	4				A current set the ship N. by W. correct magnetic, 21 miles, from the time the departure was taken to the end of the day.
8		7					
9	N.N.W.	6	5	West.	1	12° W.	
10		6	4				
11		7					
12		7	2				

EXAMPLE IV.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	S.W. ½ W.	6	5	S. by E. ½ E.	2	14½° W.	A point of land in lat. 46° 12′ S., long. 0° 5′ E., bearing by compass E. by S. ½ S., 20 miles. (Ship's head W. by compass). Deviation 9° E.
2		6	2				
3		6	6				
4		6	7				
5	N. ¾ E.	8	2	E.N.E.	¼	20° E.	
6		8	2				
7		8	6				
8		9					
9	S. by E. ½ E.	6	3	S.W. ½ W.	2¾	20° W.	
10		5	5				
11		5	6				
12		4	6				
1	W. by S.	6	4	S. by W.	2¼	5° W.	Variation 14° E.
2		6	5				
3		5	6				
4		6	5				
5	E.N.E.	6		S.E.	2½	13½° E.	
6		6	4				
7		7	6				A current set the ship W. by S. ¼ S. by compass 2½ miles per hour from the time the departure was taken until the end of the day.
8		6					
9	S.S.W. ½ W.	6	7	S.E.	1¾	18° W.	
10		6					
11		5	6				
12		5	7				

EXAMPLE V.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	W.S.W.	9	4	N.W.	½	10° W.	A point, lat. 35° 10′ N. long. 5° 36′ W., bearing by compass E. by S. Ship's head N.N.E., dist. 9 miles. Deviation 9° E.
2		9	6				
3		9	4				
4		9	6				
5	North.	11	4	W.N.W.	¼	3° W.	
6		11					
7		11	2				
8		11	4				
9	N.W.	8	4	W.S.W.	¾	17° W.	
10		8	6				
11		8	4				
12		8	6				
1	S.W. by S.	11	7	W. by N.	½	5° W.	
2		11	5				Variation 23° W.
3		11	4				
4		11	4				
5	W.S.W.	9	6	N.W.	½	10° W.	
6		9	5				
7		9	4				
8		9					
9	East.	6	4	S.S.E.	1	15° E.	
10		6	4				A current set the ship (correct magnetic) S.E. by E., 15 miles.
11		6					
12		6					

EXAMPLE VI.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	N.N.W. ½ W.	3	5	N.E.	1¾	2° W.	A point, lat. 29° 59′ N. long. 32° 54′ E., bearing by compass N.N.E. ½ E. dist. 15 miles. Ship's head N.W. by W. Deviation 6° W.
2		4	2				
3		4	3				
4	E.S.E.	2	7	N.E.	2	7° E.	
5		3					
6		3	3				
7		4					
8	S. ½ E.	5	4	E.S.E.	2½	2° W.	
9		5					
10		5	5				
11		4	5				
12		4	6				
1	N.E. ½ N.	4	7	E.S.E.	1½	8° E.	Variation 25° W.
2		4	2				
3		4	4				
4		3	7				
5		3					
6	W. ½ N.	3	5	S.S.W. ½ W.	1¼	9° W.	
7		4	3				A current set the ship (correct magnetic) N.E., 30 miles, from the time the departure was taken to the end of the day.
8		3	6				
9		3	6				
10	N. by E.	8	5	E. by N.	¼	6° E.	
11		9	3				
12		9	2				

EXAMPLE VII.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	N.N.W.	10	2	West.	¾	19¼° E.	A point, lat. 44° 20′ S., long. 178° 56′ W., bearing by compass E. by N. ¼ N., distance 18 miles. Ship's head N.N.W. Deviation as per log.
2		9	4				
3		9	4				
4		9					
5	West.	8	6	N.N.W.	1	1¼° W.	
6		8	4				
7		8	4				
8		8	6				
9	W. by S.	11	6	N.W. by N.	½	4¾° W.	
10		12	2				
11		11	8				
12		12	4				
1	S.S.W. ¼ W.	6	3	West.	1¼	17½° W.	Variation 15° E.
2		6	3				
3		6	4				
4		6					
5	South.	9	6	E.S.E.	¾	21° W.	
6		9	4				
7		9	5				A current set the ship (correct magnetic) N. by E., 18 miles, from the time the departure was taken to the end of the day.
8		9	5				
9	S. by E. ½ E.	12	5	E. by S.	¼	20° W.	
10		12	6				
11		12	5				
12		12	4				

EXAMPLE VIII.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	E.S.E.	12	4	N.E.	½	13° E.	A point, lat. 62° 18′ N. long. 63° 17′ W., bearing by compass W.N.W., distance 21 miles. Ship's head E.S.E. Deviation as per log.
2		12	5				
3		12	5				
4		12	6				
5	E. ¾ N.	4		N.N.E.	3¼	17° E.	
6		4	4				
7		4	3				
8		4	3				
9	E. ¾ S.	8	4	S.S.E.	1½	13° E.	
10		8	5				
11		8	6				
12		8	5				
1	S.W. ¾ W.	3	5	S. by E.	3¾	8° W.	Variation 60° W.
2		3	5				
3		3	4				
4		3	6				
5	S. by W.	5	3	W. by S.	2¼	0°	
6		5	3				
7		5	4				A current set the ship (correct magnetic) E. by S. ½ S., 49 miles, from the time the departure was taken to the end of the day.
8		5					
9	W.N.W.	4	2	North.	3	17° W.	
10		4	2				
11		4	2				
12		4	4				

EXAMPLE IX.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	South.	5	3	E.S.E.	1½	20° W.	A point, lat. 70° 32′ N. long. 23° 54′ W., bearing by compass N.E. ½ N., dist. 23 miles. Ship's head South, Deviation as per log.
2		4	8				
3		4	5				
4		4	4				
5	N.E. ½ N.	6	6	E. by S. ½ S.	1	8° W.	
6		6	4				
7		6					
8		6					
9	S.S.W. ½ W.	5	5	S.E. ½ S.	1½	16° E.	
10		5	6				
11		5	4				
12		5	5				Variation 53° W.
1	E. ½ S.	8		S. by E. ½ E.	¾	31° W.	
2		8	4				
3		8	4				
4		8	2				
5	S.W. ½ S.	4	6	S.S.E. ½ E.	2	15° E.	
6		5	4				
7		4	4				A current set S.E. ½ E. (correct magnetic) 2¼ miles per hour from the time the departure was taken to the end of the day.
8		4	6				
9	S.E. ½ S.	6	4	E. by N. ½ N.	1	34° W.	
10		6	3				
11		6					
12		6	3				

EXAMPLE X.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	N. by W. ¼ W.	11	4	N.E. by E.	¼	12° E.	A point, lat. 37° 42′ S., long. 178° 36′ E., bearing by compass W. by S. ¼ S., dist. 21 miles. Ship's head N. by W. ¼ W. Deviation as per log.
2		12					
3		12	4				
4		12	2				
5	N.E. ¼ N.	10	6	E. by S. ½ S.	½	21½° E.	
6		10	4				
7		10	5				
8		10	5				
9	S.E. ¼ S.	11	6	S.S.W. ¼ W.	¼	19° W.	
10		12	4				
11		12					
12		12					
1	S. by E. ½ E.	8	6	E. by S.	¾	13½° W.	Variation 14° E.
2		8	4				
3		8	5				
4		9	5				
5	N. ¾ E.	8	6	E. by N.	¾	18° E.	
6		9					
7		8	4				A current set N.E. by E. (correct magnetic) 36 miles, from the time the departure was taken to the end of the day.
8		9					
9	E. by N. ½ N.	12	4	N. ½ E.	¼	15° W.	
10		11	6				
11		12	5				
12		12	5				

EXAMPLE XI.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
1	S.E. ½ E.	10	6	E.N.E.	pts. 1¼	28° W.	A point, lat. 32°42′S., long. 4°20′ W., bearing by compass N.W. by N., distance 27 miles. Ship's head S.E. ½ E. Deviation as per log.
2		10	4				
3		10	8				
4		11	2				
5	S.S.E. ½ E.	10	4	S.W. ½ S.	1½	22° W.	
6		10	2				
7		10	4				
8		10					
9	S.E. ¼ S.	12	5	E. by N. ¾ N.	¾	28° W.	
10		12	5				
11		12	4				
12		12	6				
1	South.	10	2	W.S.W.	1¾	15° W.	Variation 28° W.
2		9	8				
3		9					
4	S.E. ½ E.	12		N.E. by E.	1½	29° W.	
5		11	6				
6		12					
7		11	8				
8		11	6				A current set S.E. by E. (correct magnetic) 38 miles, from the time the departure was taken to the end of the day.
9		12					
10	S.S.E.	12	6	S.W.	1¼	23° W.	
11		12	4				
12		13					

EXAMPLE XII.

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
1	W. by N.	9		W. by S.	pts. ½	11½° W.	A point of land in lat. 44° 20′ S., long. 176°49′ W., bearing by compass E. by N., dist. 16 miles. Ship's head W. by N. Deviation as per log.
2		10	3				
3		10	4				
4		10	3				
5	W. ½ S.	10	5	S.S.W.	1	1° W.	
6		9	5				
7		8	6				
8		8	4				
9	W.S.W.	8	5	South.	½	9¼° W.	
10		9	5				
11		9	5				
12		10	5				
1	S.W. ½ W.	8	4	S. by E.	1½	7° W.	Variation 22½° E.
2		7	6				
3		7	5				
4		7	5				
5	S. ½ W.	7	4	S.E. by E.	2	1° W.	
6		7	6				
7		8					A current set the ship W.S.W. (correct magnetic), 28 miles, from the time the departure was taken to the end of the day.
8		8					
9	West.	9	6	East.	0	12° W.	
10		10	6				
11		11	2				
12		10	6				

NAUTICAL ASTRONOMY.—DEFINITIONS.

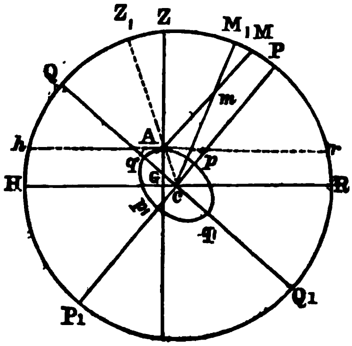
Nautical Astronomy is that branch of the subject which relates to finding the place of a spectator on the surface of the earth by observation of the heavenly bodies.

CELESTIAL SPHERE.

Celestial Concave. The *Celestial Concave* is the surface of an infinitely large sphere of which the observer's eye is the centre, and on which the motions of the heavenly bodies appear to take place.

The heavenly bodies are not in reality thus situated with respect to the spectator; for they are interspersed in infinite space at very different distances from him. The whole is an optical deception, by which an observer, wherever he is placed, is induced to imagine himself to be the centre of the universe. For let us suppose the elliptical figure *p q, p, q,* to represent a heavenly body. Then a spectator at A, not being able to estimate the distance of *m*, would imagine it to be in the celestial concave at M.

Fig. 37.



True Place. The *True Place* of a heavenly body in the celestial concave is the point in which the radius drawn from the centre of the earth to the centre of the body meets the celestial concave.

Apparent Place. The *Apparent Place* of a heavenly body is the position in the celestial concave of the centre of the body as seen by the observer.

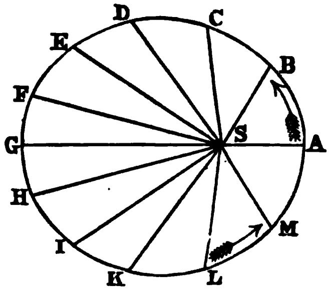
Fig. 37 enables us to explain the terms *true* and *apparent* place of a heavenly body. The body *m* viewed, from the surface of the earth, would appear to a spectator, A, to be at M in the celestial concave; but if it could be seen from the centre of the earth, C, the point occupied by *m* would be M,. The extremity of a line drawn from the centre, C, of the earth through the heavenly body to the celestial concave, M, is called the *apparent* place, and M, the *true* place of the heavenly body *m*.

Earth's Orbit.

The *Earth's Orbit* round the sun is a plane and nearly circular curve which is called an ellipse.

By observations of the sun's apparent diameter, continued throughout the year, we find that the true form of the earth's orbit is an ellipse having the sun in one of the foci. The sun's apparent diameter is least on the 1st of July, and greatest on the 1st of January. We may then construct a figure showing the form of the orbit, by setting off lines S A, S B, S C, &c., corresponding to the sun's distances, and making angles with each other equal to the sun's angular motion between the times of observation. The figure thus formed is found to be an ellipse, with the sun occupying one of the foci, as S.

Fig. 38.

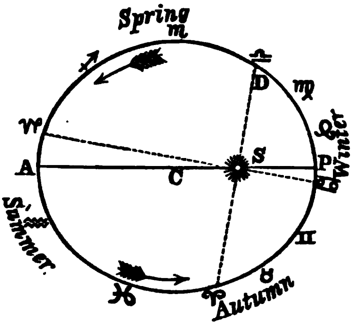


Though it is now known that the orbit is not, strictly speaking, an ellipse, yet the latter being the regular curve which is next in simplicity to a circle, astronomers, for convenience, consider it as the figure of the orbit described by the sun about the earth, or of the earth about the sun. The point G or A at which the sun or the earth is where the two bodies are at the greatest or the least distance from one another, is called an apsis, and a line joining the points of greatest and least distance is called the line of the apsides. If it be assumed that the earth revolves about the sun, the same points are respectively the aphelion and the perihelion points, the sun being supposed to be in one of the two foci of the ellipse.

The apparent annual motion of the sun may be explained either by supposing a real revolution of the sun around the earth, or a revolution of the earth around the sun. But it follows from the principles of mechanics that the earth and sun must both revolve around their common centre of gravity, and this point is very near the centre of the sun.

Appearances produced by the Earth's Annual Motion. If the earth could be observed by a spectator upon the sun, it would appear among the fixed stars in the point of the sky opposite to that in which the sun appears as viewed from the earth. Thus, in Fig. 39, let S represent the sun, and A B P D, the earth, will see the sun projected among the fixed stars in the point in the sky opposite to that occupied by the earth; and, as the earth moves from A to B and P, the sun will appear to move among the stars from P to D and A, and in the course of a year will appear to trace out in the sky the plane of the ecliptic. When the earth is in Libra we see the sun in the opposite sign Aries; and as the earth moves from Libra to Scorpio the sun appears to move from Aries to Taurus, and so on through the ecliptic.

Fig. 39.



Ecliptic. The *Ecliptic* is the great circle of the celestial concave in which the plane of the earth's orbit cuts the surface; it is the great circle on which the sun's place is to be found during the year.

The Zodiac. The *Zodiac* is the zone or belt of the celestial concave which extends 8° on each side of the ecliptic. It is divided into 12 equal regions called the signs of the zodiac.

The path described by the periodical revolution of the moon and the planets (with a few exceptions) does not deviate materially from the ecliptic, but is limited to a belt termed the *Zodiac* of about 8° on either side of the ecliptic. If we divide the ecliptic into twelve equal portions, and then draw through each of the points of division great circles perpendicular to the ecliptic, these great circles will subdivide the Zodiac into twelve equal portions. Each of these portions is represented by a certain name, which is also borne by the constellation which each portion contains.

Axis of the Heavens. The *Axis of the Heavens* is the prolongation of the earth's axis, and is that diameter about which the celestial concave appears to revolve from East to West.

Poles of the Heavens. The *Poles* of the heavens are the extremities of its axis. They are the two points of the celestial concave in which the axis of the heavens is conceived to meet its surface.

Celestial Equator or Equinoctial. The *Equinoctial* is that great circle of the celestial concave whose plane is perpendicular to the axis of the heavens. It is the great circle in which the plane of the terrestrial equator indefinitely extended intersects the celestial concave, and is hence sometimes called the *Celestial Equator*.

The Equinoctial is sometimes called the Celestial Equator, as being the great circle of the celestial concave marked out by the plane of the *terrestrial* equator indefinitely extended. It would be convenient if this compound term were altogether superseded by the simple word equinoctial; and the terrestrial equator uniformly indicated by the simple word equator.

Equinoctial Points.

The *Equinoctial Points* are the two points diametrically opposite each other in which the ecliptic intersects the celestial equator. The point at which the sun passes from the South to the North side of the celestial equator is called the *Vernal* equinoctial point, also the *First Point of Aries*, and the other is called the *Autumnal* equinoctial point. The times at which the sun's centre is found at these points are called the *vernal* and *autumnal* equinoxes. The *vernal* equinox, therefore takes place on about the 20th of March, and the *autumnal* on about the 22nd of September.

Vernal and Autumnal Equinoxes.

Solstitial Points.

The *Solstitial Points* are the two points of the ecliptic which are midway between the equinoctial points and most distant from the celestial equator. They are distinguished as the northern and southern, or the summer and winter *Solstitial Points*. The *times* at which the sun's centre passes those points are called *Solstices*. The summer solstice takes place on the 21st June, and the winter solstice on the 21st December.

Solstices.

NOTE.—It is convenient to restrict (as we have done) the term *Equinox* to indicate a *date* or epoch of *time*, and to use the expression *Equinoctial Point*, when we want to refer to a *position* or *place* in the ecliptic. Similarly for *Solstice* and *Solstitial Point*.

Obliquity of the Ecliptic.

The *Obliquity of the Ecliptic* is the angle between the ecliptic and the equinoctial.

The *Vernal Equinoctial Point* and the *Autumnal Equinoctial Point* are now more generally called the *First Point of Aries* and the *First Point of Libra*, as being the commencement respectively of these signs of the ecliptic, and they are represented by their symbols ♈ and ♎. The constellations of Aries and Libra, though not now coincident in position with them, give their names to these divisions of the ecliptic and the figure of the *Balance* (Libra) has evident reference to the equipoise of the day and night at the equinox. The first point of Aries is the origin or Zero point, from which right ascensions are reckoned on the equinoctial, and longitudes on the ecliptic.

The direction of a point may be expressed by the angles which a line drawn to it from the centre of the sphere or point of observation makes with certain fixed lines of reference. But since such angles are directly measured by arcs on the surface of the sphere, the simplest method is to assign the position in which that point appears when projected upon the surface of the sphere. For this purpose a great circle of the sphere is assumed as a *primitive circle* of reference, and all points of the surface are referred to this circle by a system of *secondaries* or *great circles* perpendicular to the primitive, and consequently passing through its pole.

The position of a point on the surface will then be expressed by two *spherical co-ordinates*, namely:—

1st. The distance of the point from the primitive circle, measured on a secondary: 2nd, the distance intercepted on the primitive between this secondary and some given point of the primitive assumed as the *origin* of co-ordinates.

We shall have different systems of co-ordinates according to the circle adopted as a primitive circle and the point assumed as the origin.

THE EQUINOCTIAL SYSTEM. *(a).*

The Primitive is the Equinoctial or Celestial Equator.

The Secondary Circles are called Circles of Declination.

Co-ordinates: Right Ascension and Declination.

Origin: Vernal Equinoctial Point.

The use of this system of co-ordinates is to define points (stars, the sun, &c.) the positions of which are independent of the observer's position.

Parallels of Declination. *Parallels of Declination* are small circles whose planes are parallel to the plane of the celestial equator.

Parallels of declination mark all the points that have the same declination N. or S.

Circles of Declination. *Circles of Declination* are great circles which pass through the poles of the heavens.

Right Ascension. The *Right Ascension* of a heavenly body is the arc of the equinoctial intercepted between the first point of Aries and the circle of declination passing through the body.

Right Ascensions are reckoned from the vernal equinoctial point eastward from 0^h to 24^h.

Declination. The *Declination* of a heavenly body is the arc of a circle of declination, which is intercepted between the equinoctial and the body.

Declination is measured from the equinoctial through an arc 0° to 90°, and is named North or South.

EQUINOCTIAL SYSTEM. *(b).*

The use of this system of polar co-ordinates is to mark at any definite moment the relative position of a heavenly body and the Zenith of the observer. The circles of declination of the celestial bodies in their daily revolution start from a fixed initial position, which is determined by the zenith of the observer. The great circle which passes through the poles of the heavens and the Zenith is called the celestial meridian of the place, and is actually the projection of the terrestrial meridian. The place of a celestial object is defined at any moment by the *angle* its circle of declination—which in this system takes the name of *Hour Circle*—makes with the celestial meridian, and the arc of this hour circle intercepted between the pole and the body.

The Primitive Circle is the Equinoctial.

The Secondary Circles are called Hour Circles.

Co-ordinates: Declination (or Polar Distance) and Hour Angle.

Hour Circles. *Hour Circles* are great circles which pass through the poles of the celestial concave. They are so called because reckoning from the celestial meridian of the place of observation, they mark all points that have the same hour-angle. Under a different conception of co-ordinates this series of circles is also called *circles of declination*, and again, *circles of right ascension*.

Hour-angle The *Hour-angle* of a celestial object is the angle at the elevated pole, included between the celestial meridian and the hour circle passing through the place of the body. The hour-angle is measured by the arc of the equinoctial intercepted between the hour circle and the meridian.

As the meridian and equinoctial intersect in two points it is necessary to distinguish which of these two points is taken as origin of hour-angles, and also to know in what direction the arc which measures the hour-angle is measured. Astronomers reckon from that point of the equinoctial which is on the meridian above the horizon towards the West—that is, in the direction of the apparent diurnal motion of the celestial sphere—and from 0° to 360°, or from 0^h to 24^h, allowing 15° to each hour.

When, however, a body is to the East of the meridian it is more correct to make use for purposes of calculation of the angle reckoned from the meridian; in this case, however, we never speak of hour-angle, but simply use the general term polar angle.

Polar Angle. The *Polar Angle* between two heavenly bodies, or two places of the same body, is the angle contained by the two hour circles which pass through them.

Polar Distance. The *Polar Distance* of a celestial object is the arc of an hour (or declination) circle which is intercepted between the elevated pole and the place of the body.

Polar distances are reckoned from the poles through 180°, and are named North or South polar distance, according as they are reckoned from the North or South Pole.

Six o'clock Hour Circle. The *Six o'clock Hour Circle* is that hour circle whose plane is perpendicular to the plane of the celestial meridian.

It passes through the East and West points.

Time Amplitude. The *Time Amplitude* is the arc of the equinoctial intercepted between the six o'clock hour circle and the hour circle passing through the place of the body when rising or setting.

THE ECLIPTIC SYSTEM.

In this system the Ecliptic is taken as the primitive circle, and the secondaries by which points of the sphere are referred to it are called *circles of latitude*, hence

The Primitive Circle is the Ecliptic.

The Secondary Circles are Circles of Latitude.

Co-ordinates: Celestial Latitude and Longitude.

Parallels of Latitude. *Parallels of Celestial Latitude* are small circles of the celestial concave whose planes are parallel to the plane of the ecliptic. They mark all the points of the heavens which have the same latitude.

Circles of Latitude. *Circles of Celestial Latitude* are great circles passing through the poles of the ecliptic, and therefore vertical to it, and so called because latitude is measured on them.

They are also called *Circles of Longitude*, as marking out all points that have the same longitude.

Celestial Latitude. *Celestial Latitude*, or the latitude of a heavenly body, is the arc of a circle of latitude intercepted between the ecliptic and the place of the body.

Celestial latitude is measured from the ecliptic through an arc of 0° to 90°.

Celestial Longitude. *Celestial Longitude*, or the longitude of a heavenly body, is the arc of the ecliptic intercepted between the first point of Aries and the circle of latitude which passes through the place of the body.

Celestial longitude is reckoned eastward from 0° to 360°, or in the direction of the sun's apparent motion in longitude.

The longitude is sometimes expressed in signs, degrees, &c.; a sign being equal to 30°, or a twelfth of the ecliptic.

These co-ordinates are also independent of the diurnal motion. It is evident, however, that the system of Declination and Right Ascension will be generally more convenient.

CAUTION.—*The student must be careful to distinguish astronomical latitude and longitude from the same terms used in geography, to which they have no resemblance but in name.* It is much to be regretted that the same terms are used, but it is extremely difficult to alter an established custom.

THE HORIZON SYSTEM.

The Primitive Circle is the Horizon.

The Secondary Circles are called Vertical Circles,
or Circles of Altitude.

Co-ordinates: Altitude and Azimuth.

As the observer changes his position on the surface of the earth the zenith changes in the celestial concave, but the pole of the heavens remains fixed. The use of this system is to connect the zenith of the observer with the fixed pole of the heavens, determined from an observation of a heavenly body. The primitive circle is, therefore, taken as that whose pole is the zenith; it is called the Celestial Horizon. Having thus chosen the *Rational Horizon* as the primitive circle of co-ordinates, the next thing to be decided upon is the point of origin. Since the object of this system is to connect the zenith with the pole, the great circle passing through both, and which is a secondary to the horizon, will, by its intersection with the latter, give us the desired point. The celestial meridian cuts the horizon in two points, called the *North* and *South Points*, and that is taken as origin which is adjacent to the elevated pole. For certain observations it is sometimes customary to choose the point most remote from the pole.

Celestial Horizon. The *Celestial Horizon* of any place is a great circle of the sphere marked out by the indefinite extension of the plane of any spectator's sensible, or which comes to the same thing, his *rational* horizon.

The Vertical Line. The *Vertical Line* is a straight line perpendicular to the horizon of the observer. It coincides with the direction of the plumb line, or the simple pendulum at rest.

Zenith. The *Zenith* is the point in the celestial concave which is vertically over the spectator's head.

Nadir. The *Nadir* is the point in the celestial concave which is vertically below the position of the spectator.

The Zenith and Nadir are the poles of the horizon, that is to say, they are 90° from every point of it.

If a plummet be freely suspended by a flexible line and allowed to come to a state of rest, this line is called a *vertical line*. That point of the heavens to which the line points, and which it would appear to reach if it could be prolonged indefinitely upwards, is the *zenith;* while if the direction of the line be prolonged downwards through the earth it will point to that part of the celestial sphere which is termed the *nadir.*

Parallels of Altitude.

Parallels of Altitude are small circles whose planes are parallel to the plane of the horizon.

Circles of Altitude.

Circles of Altitude, or *Vertical Circles,* are great circles which pass through the zenith and nadir, or great circles perpendicular to the horizon.

They are the secondaries of the horizon; and their planes, which are called *vertical planes,* intersect in the vertical line.

In a polar system of horizon co-ordinates Circles of Altitude are also termed *Circles of Azimuth,* as marking out all points that have the same azimuth.

Altitude.

The *Altitude* of a heavenly body is the arc of a vertical circle intercepted between the horizon and the centre of the body.

Zenith Distance.

The *Zenith Distance* of a heavenly body is the arc of a vertical circle intercepted between the zenith and the place of the body.

Celestial Meridian.

The *Celestial Meridian* of an observer is the great circle which passes through the zenith and the pole.

The plane of the meridian is called the *Meridian Plane.*

Meridian Line.

The intersection of the plane of the meridian with the plane of the horizon is the *Meridian Line.*

North and South Points.

The *North* and *South Points* are the points in which the celestial meridian cuts the horizon.

Azimuth.

The *Azimuth,* or true bearing of a heavenly body, is the arc of the horizon, or the angle at the zenith, between the meridian and the circle of altitude passing through the body. It is the angle comprised between two vertical planes, one passing through the elevated pole, the other through the object.

Azimuth is usually reckoned from the North or South point, eastward and westward, from 0° to 180°.

Prime Vertical.

The *Prime Vertical* is the vertical circle which crosses the meridian at right-angles.

East and West Points.

The *East* and *West Points* are the points in which the prime vertical cuts the horizon.

The East and West points are the poles of the celestial meridian.

The Poles of the Prime Vertical are therefore the North and South points.

Amplitude. The *Amplitude* of a heavenly body is the arc of the horizon, or the angle at the zenith, intercepted between the east point and the place of a body at rising, or the west point at setting.

Twilight Parallel. The *Twilight Parallel* is a small circle parallel to the horizon and 18° below it.

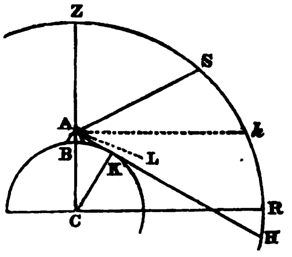
Visible Horizon. The *Visible* or *Sea Horizon* is the small circle which bounds the view of the observer, being the apparent meeting of the sea and sky.

Sensible Horizon. The *Sensible Horizon* is the plane on which the spectator stands produced to meet the celestial concave.

Rational Horizon. The *Rational Horizon* is the great circle in which the plane drawn through the centre of the earth parallel to the sensible horizon meets the celestial concave.

Dip. The *Dip* is the angle of depression of the sea horizon below a horizontal line drawn from the observer's eye.

Fig. 40.



When the altitude of a celestial body, S, above the visible horizon of a spectator is taken, it is obvious that, since the eye of the observer cannot be on the surface of the earth or water, but must be elevated above it, as at A; and since the edge of the sea horizon is the circumference of a circle on which a cone, having A for its vertex, would be a tangent to the surface, the observed altitude, S A H (the line A K H being a tangent to the earth's surface in a vertical plane passing through the observer and the celestial body, and the effects of refraction being neglected), will exceed the altitude, S A *h*, by the angle *h* A H, called the dip of the horizon, or by its equal, A C K. Hence a correction must be made for this dip or depression, and it may be found from the triangle A C K, in which A B (the height of the spectator above the surface) being given, as well as the semidiameter of the earth, we have A C, C K, and the right-angle at K, to find the angle A C K, or its equal, H A *h*.

But the dip of the horizon is evidently affected by the refraction of the rays of light in passing from the edge of the sea to the eye of the spectator, in consequence of which the sea horizon generally appears to be higher than it is in reality; and a like source of error exists in the observed angular elevations and depressions of objects on land.

Refraction. *Refraction* of a heavenly body is the angle at the eye of the observer between a line drawn to the centre of the body and a tangent to the curved ray of light where it enters the eye.

Before the observed positions of celestial bodies can be employed as data for the solution of astronomical or geographical problems, they require corrections on account of the refraction of light in the atmosphere, and also on account of the situation of the observer with respect to the earth's centre.

Parallax.

The *Parallax* of a celestial body is the angle subtended at the body by that radius of the earth which is drawn to the feet of the observer.

The fixed stars are so distant from the earth that their relative positions are sensibly the same, from whatever point of the earth's surface we may view them. It is otherwise with the sun, moon, and planets, which are near enough (especially the moon) to be displaced by change of station on our globe. Two spectators, situated on different points of the earth's surface and viewing the moon do not see it in the same direction.

The word *parallax* is used to express the angle at any celestial body between two lines drawn from its centre to the points from whence it may be supposed to be viewed: or it is the arc of the celestial sphere between the two places, which a body would, at the same instant, appear to occupy if it were observed at two different stations. The celestial arc between the sun and moon, or between the moon and a star at any instant, will evidently subtend different angles at the eyes of two observers at different stations on the surface of the earth; and in order that a common angle may measure the same arc, it is necessary that each observed angle should be reduced to that which would be subtended by the same arc at the centre of the earth. When the arc measures the altitude of a celestial body above the visible horizon, the correction which must be applied in order to convert the observed angle of elevation to that which would have been obtained if the angular point had been at the centre of the earth, is called the *diurnal parallax*. This name has been given to it because it goes through all its variations between the times at which the body rises and sets, being greatest when the latter is on the horizon, and least when in the plane of the meridian; and since every parallax is necessarily in a plane passing through the two points of observation and the object, it is evident that the diurnal parallax will be in a plane passing through the observer and the centre of the earth.

The angular distance between two places to which, in the heavens a celestial body is referred when it is supposed to be viewed from the sun and from the earth, or of the earth at two different points in its orbit, is called the *annual parallax*.

Semidiameter.

The *Semidiameter* of a heavenly body is the angle subtended at the eye of the observer by the radius of the disc.

In order to obtain by observation the position of a celestial body which has a well-defined disc, we observe the position of some part of the limb and deduce that of the centre by a suitable application of the angular semidiameter of the body. The sun's semidiameter is given in the *Nautical Almanac*, page II of each month, for every day at noon, and that for the moon at page III for every day at noon and midnight. The semidiameter there given is the *angle at the centre* of the earth subtended by the semidiameter of the object, and because the observer being on the surface is *nearer* the object in every position, except when it is in the rational horizon, this angle requires a correction.

Augmentation of the Moon's semidiameter. *The Augmentation of the Moon's semidiameter* is the increase of the moon's semidiameter arising from the decreased distance from the moon as her altitude increases.

Observed Altitude. *The observed altitude* of a heavenly body is the altitude of a body from the sea horizon read from the arc of the instrument by which the altitude has been measured.

Apparent Altitude. *The apparent altitude* is the observed altitude when corrected for index error, dip, and semidiameter; that is the altitude of the apparent place of the object's centre from the sensible horizon.

"*Apparent*" is sometimes used as a qualification, distinguishing on the one hand from *observed*, and on the other from *true*. It is in this sense applied to elements corrected for instrumental and circumstantial sources of error, but not yet reduced for comparison and computation. We have thus the apparent altitude of a heavenly body, and the apparent distance of two heavenly bodies, distinguished on the one hand from the *observed*, and on the other from the *true* altitude and distance.

True Altitude. When the apparent altitude has been corrected for refraction and parallax, the result is called the *true altitude*: that is the altitude of the true place of the body from the rational horizon.

Since time enters as an element in most of the problems in nautical astronomy, it will be proper now to explain the kinds which are employed, and the manner of reducing a given interval in time from one denomination to another. Three different kinds of time are employed by astronomers; *Sidereal, Apparent or True Solar, and Mean Solar Time.*

Diurnal Time. *Diurnal Time* is simply the hour-angle of particular points in the heavens which are chosen to define it. The unit of time is the period which elapses from the hour circle of the point of definition coinciding with the celestial meridian and its next return to it after one revolution; such interval is called a *day*. The commencement of the day, when the hour circle of the point of definition and the meridian are coincident, is called *noon*. The unit is divided into 24 equal parts, called *hours*, which are subdivided into *minutes* and *seconds*; these are indicated by the letters *h m s*.

There are three points of definition used by astronomers. The *Centre of the Sun*, an imaginary point called the *Mean Sun* and the *First Point of Aries*.

When the centre of the sun is used as the point of definition we get what are termed *Apparent Solar Time*, *Apparent Day*, and *Apparent Noon*.

Apparent Solar Time.

Apparent Solar Time is the hour-angle of the actual sun, a body which is apparent to our sense of sight, measuring from the meridian westward.

The time which is denoted by the true sun is called the *true*, or more commonly the "*Apparent Time.*"

Apparent Solar Day.

An Apparent Solar Day or briefly *Apparent Day*, is the interval of time between two successive upper transits of the actual sun's centre, or hour circle, over the same celestial meridian; it begins when that point is on the meridian.

For the sake of simplicity of calculation, as also for being convenient for the purposes of civil life, astronomers employ a diurnal rotation of the earth with respect to the sun as a measure of time. Now the earth being supposed to revolve about the sun with its true or proper annual motion, each of the intervals between the instants at which, successively, by the earth's rotation on its axis, the plane of a terrestrial meridian when produced passes through the centre of the sun, is considered as the length of the apparent solar day; and it is found that the number of such revolutions or days in the mean tropical year is 365·242217. The obliquity of the terrestrial equator to the plane of the ecliptic, considered as fixed, is here supposed to suffer no variation, and the line of the equinoxes to continue parallel to itself except the uniform angular deviation from parallelism which is due to the effect of general precession (= 50″·2 yearly.)

Apparent Noon.

Apparent Noon is the instant when the true sun's hour circle coincides with the celestial meridian.

The arrival of the sun at the plane of a terrestrial meridian constitutes noon on that meridian.

Apparent time and apparent noon are elements which are much used in Nautical Astronomy, and are of so much importance that as soon as the navigator is at sea he adopts as his unit of time the apparent solar day. Apparent noon is the instant when he can most easily and expeditiously determine his latitude, and his ordinary habitual method of finding his longitude is by an observation from which by calculation it is necessary for him in the first place to deduce the apparent time. But there is a feature of apparent time which renders it unsuitable as a standard, and prevents its being used as a standard of comparison—it is variable. If the sun changed its R.A. uniformly, apparent solar days, though not equal to sidereal days, would still be equal to each other; but the length of these solar days are unequal, both because the motion of the earth in its orbit is variable, and because the plane of the orbit is not perpendicular to the axis of the diurnal rotation.

It is evident the sun's increase of right ascension must be variable on account of the obliquity of the ecliptic to the equator; because when the sun is in Aries, its motion being oblique to the equator, the rate of increase of right ascension must then be less than the rate of increase of longitude; when at the tropics its motion is parallel to the equator; and being nearer the pole of the equator than the pole of the ecliptic, the arc of the equator between two successive circles of declination will be greater than the arc of the ecliptic, and, consequently, its motion in right ascension must be then greater than its motion in longitude. Hence it is evident that the length of a solar day must be variable, and consequently that the time which is called apparent solar time, or apparent time measured by a solar day, and parts of a day, must require a correction which is called the Equation of Time.

If the sun, instead of moving as it does unequally in the ecliptic, moved uniformly in the equator, the interval between two transits of the sun over the meridian would then be always the same, and would be an exact measure of time.

Let us suppose, then, an imaginary sun moving uniformly in the equator in the same time in which the sun appears to move in the ecliptic and having its right ascension or distance from the First Point of Aries, equal to the mean longitude of the sun (or the longitude of the sun supposed to move uniformly in the ecliptic). The time measured by this imaginary sun so moving is called *mean solar time*, or mean time. The hour-circle passing through the imaginary sun describes 360° in 24 hours mean time, and that through the real sun the same in 24 hours apparent time, therefore each describes 15° in an hour.

The second point of definition for time is an imaginary point called the *Mean Sun*.

Mean Sun.

The Mean Sun is an imaginary body, conceived to move uniformly in the equinoctial with the mean motion of the actual sun in the ecliptic.

Mean Solar Time.

Mean Solar Time is the hour-angle of the mean sun.

As the time deduced from observations of the *true* sun is called "*true*," or "apparent time," so the time deduced from the *mean* sun is denominated "mean time;" and since the latter lapses uniformly it may for practical purposes be measured or indicated by machinery. We thus use on shore a Mean Solar Clock, and at sea a Chronometer.

Mean Day.

A Mean Day is the interval between two successive transits of the mean sun's hour circle across the same celestial meridian.

The length of this unit is the average or mean length of the apparent solar days for the period of a solar year. The length of the mean solar day may be divided into twenty-four equal parts, or hours, or the half of it into twelve hours; and a clock whose dial-plate is divided into twelve hours being regulated so that the hour-hand may make a complete revolution on the plate, in the time of half the mean solar day, as above described, is a perfect indicator of mean solar day.

Mean Noon.

Mean Noon is the instant when the mean sun's hour circle coincides with the meridian.

Equation of Time.

The *Equation of Time* is the arc of the equinoctial intercepted between the hour circles passing through the places of the true and mean suns. It is the difference between apparent and mean time, and in the *Nautical Almanac* its value is given for the instants both of apparent and mean time at Greenwich on every day in the year.

The Equation of Time is so called because it enables us to reduce apparent to mean, or mean to apparent time. In consequence of the motion of the sun in the ecliptic being variable, and the ecliptic not being perpendicular to the axis of the earth's rotation, apparent time is variable, and this fluctuation is considerable, amounting to upwards of half an hour—apparent noon sometimes taking place as much as 16^m before mean noon, and at others as much as $14\frac{1}{2}^m$ after. These are the greatest values of the equation of time; it vanishes altogether four times a year—this occurring about April 15th, June 15th, September 1st, and December 24th. It is calculated and inserted in the *Nautical Almanac* for every day in the year. On page I of each month the equation of time given is that to be used in deducing mean from apparent time; that on page II is to be used in deducing apparent from mean time. The difference in the value of the two arises from the one being that at apparent noon, and the other that at mean noon. As these may be separated by an interval of more than a quarter of an hour, the equation of time given in pages I and II may differ by a quarter of the "Var. in 1 hour" given in the adjoining column. The equation of time is itself a portion of mean time.

The third point of definition for time is the *First Point of Aries*, the origin of the co-ordinates, right ascension, and declination. By using the time marked by its motion we may render available an observation of a star in the same manner that apparent time is used with observations of the sun, to this end, however, we must have a link to connect it with mean time analogous to the equation of time. This element is fixed upon and is *the Sidereal Time at Greenwich Mean Noon;* it is calculated before hand and tabulated in the *Nautical Almanac* under the heading "*Sidereal Time.*"

Sidereal Time. *Sidereal Time* at any instant is the hour-angle of the true *vernal equinox* or *First Point of Aries* at that instant, reckoned from the meridian westward from 0^h to 24^h.

Sidereal Day. A *Sidereal Day* is the interval of time between two successive transits of the hour circle of the *First Point of Aries* across the same celestial meridian.

NOTE.—The effect of precession and nutation upon the time of transit of the vernal equinox is so nearly the same at two successive transits that sidereal days thus defined are sensibly equal.

Sidereal Noon. *Sidereal Noon* is the instant when the hour circle of the *First Point of Aries* is on the meridian.

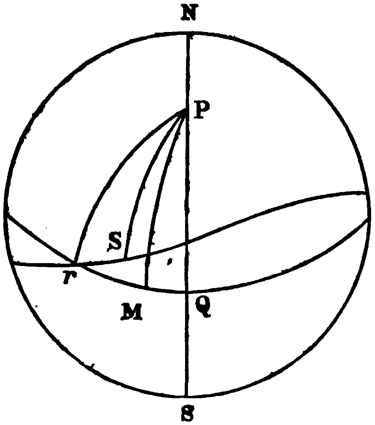
When the *First Point of Aries* (♈) is on the meridian, the sidereal time is $0^h\ 0^m\ 0^s$, and this instant is sometimes called *Sidereal Noon.*

Sidereal Time at Mean Noon. *Sidereal Time at Mean Noon* is the angular distance at the First Point of Aries from the meridian of Greenwich at the instant of mean noon, (M P r). It is therefore the same (though reckoned in the opposite direction) with right ascension of the mean sun when it is mean noon at

Greenwich (♈ M). The sidereal time at mean noon given in the *Nautical Almanac*, page II of the month, is the time shown by a sidereal clock at Greenwich, when the mean solar clock indicates $0^h\ 0^m\ 0^s$.

"The right ascension of the mean sun" must not be confounded with the right ascension of the sun at mean noon.

Fig. 41.



Let S be the place of the sun in the ecliptic, and M the mean sun; through S and M draw the circles of declination P S and P M. The *sidereal time* is the angle Q P ♈, or arc Q ♈, *apparent solar time* is the angle Q P S, and *mean solar time* is the angle Q P M, or arc Q M, these angles or arcs being always measured from the meridian N S; also, the angle M P S is the *equation of time*.

Acceleration of Sidereal on Mean Solar Time.

Acceleration of Sidereal on Mean Solar Time is the change of the mean sun's right ascension, in consequence of which, in the interval of his coming successively to the meridian, the First Point of Aries appears to have hastened forward in its diurnal revolution; hence the name. Let M P V (Fig. 42) be the sidereal time, when the mean sun is on the meridian of Greenwich on a particular day. When the mean sun comes after the lapse of a mean solar day he will have moved in right ascension to the eastward, say through M M′ (Fig. 43). The sidereal time corresponding to this second mean noon will be M′ P V instead of M P V, the First Point of Aries thus appearing to have hastened forward in its diurnal revolution, and the sidereal

Fig. 42.

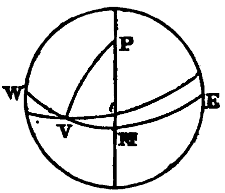
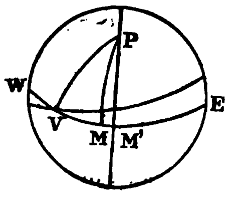


Fig. 43.

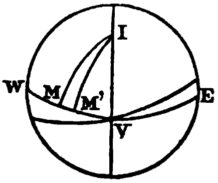


time to be accelerated with reference to mean solar time. The angle M′ P M, which is the acceleration, is a portion of sidereal time. The amount of acceleration for any given interval of mean solar time will enable us to deduce the sidereal time. In the *Nautical Almanac* for 1888, pages 484 and 485, is given a "Table for converting intervals of mean solar time into equivalent intervals of sidereal time." Similar tables are also given in treatises on navigation (Raper, Table 23; Norie, Table XXXVIII).

Retardation of Mean Solar on Sidereal Time.

Retardation of Mean Solar on Sidereal Time is the change of the mean sun's right ascension in a sidereal day, in consequence of which he appears to hang back in his diurnal revolution.

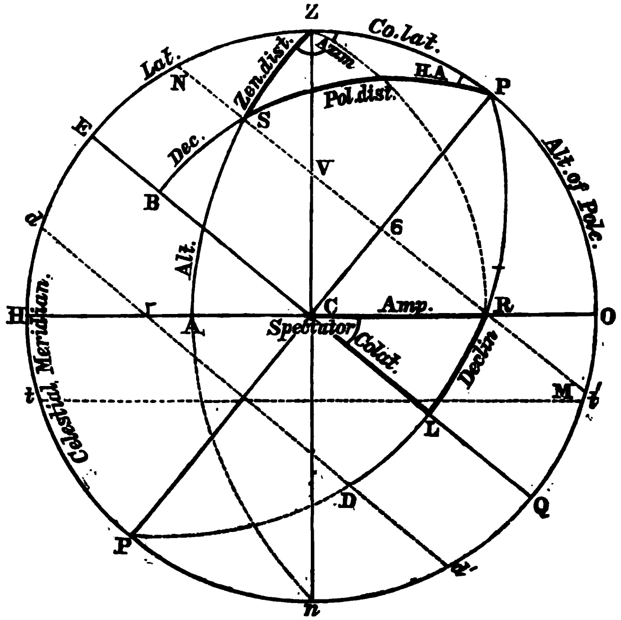
Fig. 44.



Let V be the First Point of Aries on the meridian on any given day, and V I M the corresponding mean solar time. When the First Point of Aries comes again to the meridian after the lapse of a sidereal day, the mean sun will have moved to the eastward by reason of his proper motion in right ascension through the arc M M′ say. Thus in the diurnal revolution from East to West the mean sun will be at M′ instead of at M, appearing thereby to hang back, and the mean solar time to be retarded with reference to sidereal time. The angle M I M′, which is the retardation, is portion of mean solar time. The amount of retardation for any given interval of sidereal time will enable us to deduce the mean solar time. In the *Nautical Almanac* for 1888, pages 486-487, is given a "Table for correcting intervals of sidereal time into equivalent intervals of mean solar time." Similar tables are also given in treatises on navigation (Raper, Table 24, Norie, XXXVII.

PROJECTION OF THE CELESTIAL SPHERE ON THE PLANE OF THE OBSERVER'S MERIDIAN.

Fig. 45.



The foregoing figure (Fig. 45) is a projection of the *Celestial Sphere on the Plane of the Observer's Meridian*, in which the circle Z O *n* H is the Meridian, and the observer is supposed to be stationed in the apparent centre C.

Then, the point C being taken as the East or West point of the horizon, is 90 degrees distant from every point of the Meridian, and is therefore the pole of that great circle; and all great circles H O, Z *n*, P P′, and E Q passing through E are at right-angles to the meridian, and appear on this projection as straight lines; and we have:—

H O is the *Horizon*, which here appears as a straight line, the spectator being supposed to look in the direction of the plane of this circle, as at the edge of a circular card held horizontally before his eye.

O is the *North*, and H the *South* point of the horizon.

P is the *North Pole* } All circles which meet those points are circles of
P′ is the *South Pole* } declination, or hour circles.

Z is the *Zenith* or point vertically over the observer's head.

n is the *Nadir* or point beneath the observer opposite the *Zenith*.

E Q is the *Celestial Equator*, and since it is a great circle passing through E, appears in this projection as a straight line.

Z C *n* the vertical circle at right-angles to the meridian, is called the *Prime Vertical*.

P C P′ the hour circle at right-angles to the meridian, is called the *Six o'clock Hour Circle.*

P O the *Altitude of the Pole.*

Since P E = Z O = 90°, if Z P be omitted Z E = P O, but Z E measures the latitude of the place whose Zenith is Z, therefore, P O, or *the altitude of the elevated pole is equal to the latitude of the observer.*

P Z is the *Co-latitude*, or *Complement of Latitude.*

S is a *Celestial Body.*

S B is its *Declination*, P S its *Polar Distance.*

S A its *True Altitude*, Z S its *Zenith Distance.*

The angle Z P S is the *Hour-angle* or *Meridian Distance.*

S Z P its *Azimuth* from the North in North Latitude, or from the South in South Latitude.

The arc E B also measures the *Hour-angle.*

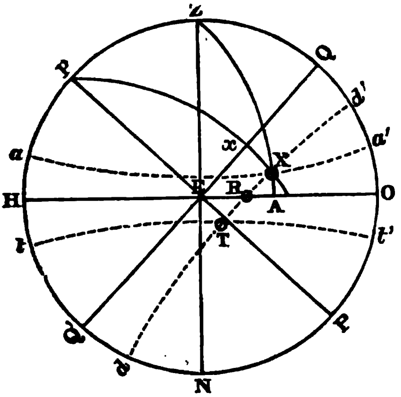
H A or A O also measures the *Azimuth.*

If an object rise or set at R, C R or the angle C Z R is called its *Amplitude.*

PROJECTION ON THE PLANE OF THE MERIDIAN.

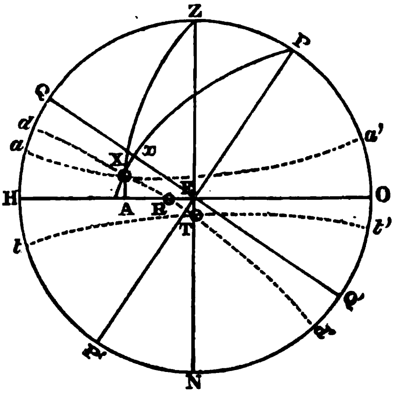
A body X having S. declination, seen in the Northern Hemisphere.

Fig. 46.



A body X having N. declination, seen in the Southern Hemisphere.

Fig. 47.



P and P′ are the *North* and *South Poles.*

Z and N are the *Zenith* and *Nadir.*

H O is the *Horizon.*

a a′ is a *Parallel of Altitude.*

R is *Rising Body.*

O A is the *Azimuth* of X.

A X is the *Altitude* of X.

Z X is the *Zenith Distance* of X.

d d′ is a *Parallel of Declination.*

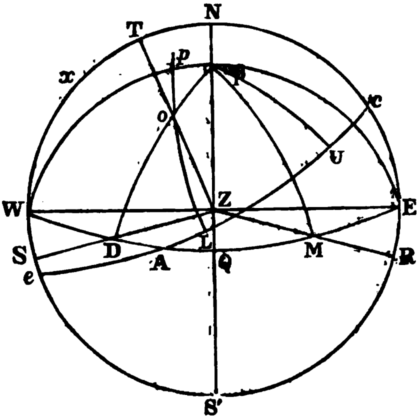
t t′ is the *Twilight Parallel.*

A PROJECTION UPON THE PLANE OF THE HORIZON.

The following figure represents the projection of the celestial sphere on the plane of the horizon.

The principal advantage of this projection is that it exhibits at one view the whole hemisphere which is above the horizon.

Fig. 48.



The horizon, N E S′ W, in this case appears as a circle, and the spectator must suppose himself looking down upon it from the Zenith Z; and all circles passing through the Zenith will appear as straight lines: thus we have—

N, the North Point; E, the East Point; S′, the South Point; W, the West Point.

P is the Elevated Pole, and N P the Elevation of the pole equal to the latitude of the place of observation.

N Z S′ is the *Meridian* of the observer's position, cutting the horizon in the North and South points; E and W are the poles of the meridian, for they are 90° distant from every point in that circle.

W Z E, the vertical circle at right-angles to the meridian, is called the *Prime Vertical.*

W Q E is the *Equator* or *Equinoctial.*

W P E is the *Six o'clock Hour Circle.*

Z *o* T, Z M R are *Circles of Altitude* or *Vertical Circles.*

o T is the *Altitude* of a body *o*.

Z *o* is *Zenith Distance* of complement of altitude of *o*.

P *o* D is a *Circle of Declination.*

o D is the *Declination* of a body *o*.

P *o* is its *Polar Distance.*

P Z *o* is the *Azimuth.*

o P Z is the *Hour-angle*, or *Meridian Distance.*

e A *c* is the *Ecliptic*, and A the *Equinoctial Point.*

o L is the *Latitude* of *o*.

A L is the *Longitude* of *o*.

A D or the angle A P D is the *Right Ascension.*

If an object rose at R and set at S, then E R would be its *rising* amplitude, and W S its *setting* amplitude.

PRELIMINARY RULES IN NAUTICAL ASTRONOMY.

CIVIL AND ASTRONOMICAL DAY.

138. The **Civil Day,** or common method of reckoning time, begins at midnight, and ends the following midnight, the interval being divided into two periods of 12 hours each; the first twelve hours, from midnight to noon, are denoted by A.M. *(ante meridian)*; the latter, from noon to midnight, are styled P.M. *(post meridian)*; thus we say 10 A.M. when an event occurred at 10 o'clock in the morning, and 10 P.M. when it occurred at 10 o'clock in the evening.

139. The **Astronomical Day** begins at noon and ends at the following noon, and is later than the civil day by twelve hours. The hours are reckoned throughout, or continuously from 0^h to 24^h. The distinction of A.M. and P.M. is not recognised in astronomical time. Thus 11 o'clock in the forenoon of the second of January in the civil reckoning of time corresponds to January 1 day 23 hours in the astronomical reckoning; and 1 o'clock in the afternoon of the former to January 2 days 1 hour of the latter reckoning.

140. Since the civil day commences at the midnight *preceding* the noon which commences the astronomical day, it is evident that the civil mode of reckoning is always twelve hours in advance of the astronomical reckoning, and hence we have the following rule for converting civil into astronomical time.

Given civil time at ship, to reduce it to astronomical time.

RULE LIV.

1°. *If the civil time at ship be* P.M., *it will also be astronomical time,* P.M. *being omitted.*

2°. *If the civil time be* A.M., *add twelve to the hours and subtract one from the days of the month; also omit* A.M. The result in each case is the Astronomical Date.

EXAMPLES.

Ex. 1. May 10th, at $5^h 30^m$ P.M., civil time is $5^h 30^m$ astronomical time of the same date; because the 10th astronomical day begins at noon of the 10th civil day, and $5^h 30^m$ have elapsed since that noon. But $5^h 30^m$ A.M. civil time on May 10th is $17^h 30^m$ *astronomical* time on the 9th of May, for the 9th day of the month, according to the astronomical reckoning, commences at noon of the 9th civil time, and ends at noon of the 10th civil day (the hours being reckoned up to 24), and $5^h 30^m$ A.M. of the 10th is $17^h 30^m$ from noon of the 9th.

Ex. 2. October 7th, at $3^h 20^m$ P.M., civil time, is October 7th, at $3^h 20^m$ astronomical time. (See 1° of Rule LIV.)

Ex. 3. October 7th, at $3^h 20^m$ A.M., civil date, is October $6^d\ 15^h 20^m$ astronomical date; since 7^d less 1^d is 6^d, and 12^h added to $3^h 20^m$ is $15^h 20^m$. (See 2° of Rule.)

Ex. 4. January 31st, at $7^h 20^m$ P.M., civil time, is January 31st, at $7^h 20^m$ astronomical time. (Rule LIV, 1°.)

Ex. 5. February 1st, at $6^h\ 18^m$ A.M., civil date, is January $31^d\ 18^h\ 18^m$ astronomical date; since February 1^d, diminished by 1^d, gives January 31^d, and 12^h added to $6^h\ 18^m$ is $18^h\ 18^m$. (Rule LIV, 2°).

Ex. 6. What is the astronomical date corresponding to 1889, January 1st, 8^h A.M.? The corresponding astronomical date is 1888, December $31^d\ 20^h$. In this case the year is diminished by 1, since in diminishing the day of the month by 1, the reckoning throws us back into the last month of the previous year, *i.e.*, the day before January 1st, 1889, also 12^h added to 8^h is 20^h.

Examples for Practice.

Express the following dates in astronomical time.

1. Jan. 2nd, $4^h\ 38^m\ 9^s$ A.M.
2. Feb. 27th, 8 12 0 P.M.
3. April 1st, 7 54 19 A.M.
4. July 1st, 8 3 24 P.M.
5. July 1st, $11^h\ 30^m\ 10^s$ A.M.
6. Oct. 1st, 0 10 12 P.M.
7. 1888, Jan. 1st, 8 9 50 A.M.
8. 1889, Jan. 1st, 0 44 12 A.M.

141. Given the astronomical date, to find the corresponding civil date.

RULE LV.

If the hours of astronomical time be less *than* 12^h *write* P.M. *after it, and it will be the required civil time; but if the* astronomical time *be greater than* 12^h, add 1 *to the* days, diminish *the* hours *by* 12 *and write* A.M. *after it:* the result will be the required civil time.

Express the following astronomical dates in civil time:—

1. Jan. 10th, $16^h\ 31^m\ 15^s$
2. Feb. 3rd, 11 28 56
3. May 17th, 7 15 11
4. Mar. 13th, 23 15 7
5. Sept. 1st, $8^h\ 10^m\ 54^s$
6. Aug. 31st, 20 10 54
7. 1888, Jan. 1st, 9 50 41
8. 1888, Dec. 31st, 22 41 56

LONGITUDE IN ARC AND LONGITUDE IN TIME.

142. The earth rotates uniformly on her axis once in twenty-four hours, and thus every spot on her surface describes a complete circle, or 360°, in that space of time; hence the longitude of any place is proportional to the time the earth takes to revolve through the angle between the first meridian and the meridian of the place, and thus the longitude of a place may be expressed either in *arc* or in *time*.[*] Longitude in arc and longitude in time are easily convertible, for since 360° is equivalent to 24^h ($360 \div 24 = 15°$), 15° is equivalent to 1^h, $15'$ to 1^m, and $15''$ to 1^s; whence

$1°$ is equivalent to 4^m (*i.e.*, the 15th part of 1 hour or 60^m)
$1'$,, 4^s (*i.e.*, the 15th part of 1 minute or 60^s)
$1''$,, 4^t (*i.e.*, the 15th part of 1 second or 60^t)[†]

and the following rules are sufficiently clear.

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[*] In reckoning by arc, each degree is divided into sixty minutes, and each minute into sixty seconds. In reckoning by time, each hour is also divided into sixty minutes, and the minutes into sixty seconds. But a distinct notation for each of these has been adopted, degrees, minutes, and seconds being represented by $^{\circ}\ '\ ''$, and hours minutes, and seconds by $^{h\ m\ s}$; and care should be observed not to use the same marks for both, great confusion arising from so doing.

[†] A third is the name given to the sixtieth part of a second.

143. To convert arc (or longitude) into time.

RULE LVI.

Multiply the degrees, minutes, &c., by 4*; this turns the degrees* (°) *into minutes* (^{m}) *of time, minutes* (′) *into seconds* (^{s}) *of time, and the seconds* (″) *into thirds* (^{t}) *of time;* or in other words, mark the resulting figures thus:—*Those under seconds* (″) *thirds* (^{t}), *those under minutes* (′) *seconds* (^{s}), *those under degrees* (°) *minutes* (^{m}), *and those to the left of the latter, hours* (^{h}).

NOTE.—Instead of thirds it is customary to use tenths of seconds, in which case the thirds must be reduced to tenths by dividing by 60.

EXAMPLES.

Ex. 1. Convert 12° 18′ 15″ into time.

$$\begin{array}{r} 12^\circ\ 18'\ 15'' \\ 4 \\ \hline 49^m\ 13^s\ \ 0^t \end{array}$$

Four times 15″ are 60″, which contains 60 once and 0 over; write this remainder down under the seconds (″) and mark it thirds (t) as directed in the Rule, carrying the 1. Again 4 times 18′ are 72, and the 1′ carried makes 73; 60 goes in 73 once and 13 over; write this remainder (13) under the minutes (′) and call them seconds (s) and carry the 1. Again, 4 times 12 are 48, and 1 carried makes 49; write this under degrees (°) and mark it minutes (m): whence the time corresponding to arc 12° 18′ 15″ is $49^m\ 13^s\ 0t$.

Ex. 2. Convert 25° 15′ 16″ into time.

$$\begin{array}{r} 25^\circ\ 15'\ 16'' \\ 4 \\ \hline 1^h\ 41^m\ \ 1^s\ \ 4^t \end{array}$$

Four times 16″ are 64″, which contains 60 once and 4 over, and according to Rule this remainder placed under seconds (″) becomes thirds (t), and the 1 is to be carried. Again, four times 15′ are 60 and 1 carried makes 61, which contains 60 once and 1 over; write the remainder 1 under minutes (′) and call them seconds (s), and carry 1: four times 25 are 100 and 1 carried gives 101, and 60 into 101 goes once and 41 remainder, which remainder being placed under degrees (°) gives minutes (m) and the 1 carried on being placed to the left of the latter is marked hours (h); whence $1^h\ 41^m\ 1^s\ 4t$ is the time corresponding to the arc 25° 15′ 16″.

Ex. 3. Turn 77° 2′ 10″ into time.

$$\begin{array}{rr} 77^\circ\ 2'\ 10'' & 60)40^t\cdot0 \\ 4 & \\ \hline 6,0)30,8^m\ 8^s\ 40t & \cdot66 \\ \hline \text{or, } 5^h\ 8^m\ 8^s\cdot66 & \end{array}$$

Ex. 4. Convert 178° 45′ 53″ into time.

$$\begin{array}{rr} 178^\circ 45'\ 53'' & 60)32^t\cdot00 \\ 4 & \\ \hline 6,0)71,5^m\ 3^s\ 32^t & \cdot53 \\ \hline \text{or, } 11^h\ 55^m\ 3^s\cdot53 & \end{array}$$

EXAMPLES FOR PRACTICE.

Reduce the following arcs into time:—

1. 18° 54′; 12° 40′ 45″; 137° 27′; 96° 10′ 45″; and 89° 16′.
2. 0° 58′·6; 49° 4′ 20″; 0° 26′·8; 2° 18′ 12″; and 130° 19′.
3. 0° 13′·5; 51° 10′ 12″; 156° 52′; 178° 49′ 45″; and 0° 41′·7.

TO CONVERT TIME INTO LONGITUDE.

144. It has been shown (No. 142, page 176) that 4^m of time are equivalent to 1° of arc; hence it is evident that if we bring any given time into minutes, and divide by 4, we shall have the corresponding arc in degrees, minutes, and seconds. This is the reverse of the last process.

RULE LVII.

Reduce the hours and minutes into minutes, after which place the seconds, &c., then divide all by 4, *and the quotient will be the degrees, minutes, &c., of the corresponding arc;* or, in other words, after dividing by 4, mark the resulting figures thus:—*Those under minutes* (^{m}) *degrees* (°), *those under seconds* (^{s}) *minutes* (′), *those under thirds* (^{t}) *seconds* (″).

EXAMPLES.

Ex. 1. Turn $1^h\ 5^m\ 12^s$ into arc.

$1^h\ 5^m 12^s$
60
$4)65^m 12^s\ 0^t$
$16^\circ 18'\ 0''$

Multiply 1^h by 60, add the minutes (5) and divide by 4, the quotient is 16° with remainder 1. Multiply this remainder by 60, and to the product add the 12 seconds; the sum is 72. Again, the quotient of 72 divided by 4 is 18, which is minutes ('); whence the arc corresponding to the time $1^h\ 5^m\ 12^s$ is $16^\circ\ 18'$.

Ex. 2. Reduce $6^h\ 24^m\ 43^s$ into arc.

$6^h 24^m 43^s$
60
$4)384^m 43^s\ 0^t$
$96^\circ 10'\ 45''$

Multiplying 6^h by 60, and adding the 24^m to the product, gives 384 as the sum; the quotient of this divided by 4 is 96°, with no remainder. 43^m divided by 4 gives quotient 10' with remainder 3: remainder 3 multiplied by 60 gives 180, which divided by 4 gives quotient 45''; therefore, $96^\circ\ 10'\ 45''$ is the arc which corresponds to $6^h\ 24^m\ 43^s$.

Ex. 3. Convert $8^h\ 17^m\ 35^s{\cdot}5$ into arc.

$8^h 17^m 35^s{\cdot}5$ $\qquad {\cdot}5$
60 $\qquad 6$
$4)497^m 35^s\ 30^t$ $\qquad 30$
$124^\circ 23'\ 52''{\cdot}5$

Multiply the hours (8^h) by 60, and adding the minutes (17^m) to the product gives 497^m; divide the result by 4, the quotient is 124 with remainder 1. Again, multiply the remainder just obtained (1°) by 60, and to the product add the seconds of time, viz., 35^s, the sum is 95; then divided by 4 the quotient is 23' (minutes of arc) with remainder 3. Next multiply this last remainder by 60, the product is 180, to which add the 30t; and the sum 210 divided by 4 gives 52'' of arc, and remainder 2, to which annex a cypher and divide by 4, the quotient is ·5 of seconds of arc.

Ex. 4. Convert $11^h\ 39^m\ 50^s{\cdot}7$ into arc.

$11^h 39^m 50^s{\cdot}7$ $\qquad {\cdot}7^s$
60 $\qquad 6$
$4)699^m 50^s\ 42^t$ $\qquad 42$
$174^\circ 57'\ 40''{\cdot}5$

Multiply 11^h by 60, and to product 660 add 39^m, dividing the sum, viz., 699 by 4 gives 174°, with remainder 3; this remainder (3) multiplied by 60, and 50^s added to product gives 230; this sum divided by 4 gives 57°, with remainder 2; remainder 2 multiplied by 60, and 42^s added, gives sum 162, which divided by 4 gives 40''; and remainder 2; remainder 2 with a cypher annexed and divided by 4, gives quotient ·5; whence the arc corresponding to $11^h\ 39^m\ 50^s{\cdot}7$ is $174^\circ\ 57'\ 40''{\cdot}5$.

Ex. 5. What arc corresponding to $0^h\ 47^m\ 36^s$?

$4)0^h\ 47^m\ 36^s$
$11^\circ\ 54'$

In this instance it is not necessary to multiply by 60, as there are no hours to reduce into minutes: we divide 47^m at once by 4.

Ex. 6. What is the equivalent arc to $9^h\ 25^m\ 37^s$?

$9^h\ 25^m\ 37^s$
60
$4)565^m\ 37^s\ 0^t$
$141^\circ 24'\ 15''$

EXAMPLES FOR PRACTICE.

Convert the following times into arc:—

1. $1^h\ 13^m\ 52^s$
2. 3 52 4
3. 0 42 12
4. $9^h\ 49^m\ 38^s$
5. 0 34 58·2
6. 0 21 30·9
7. $11^h\ 41^m\ 6^s{\cdot}66$
8. 0 3 52
9. 0 0 52
10. $5^h\ 0^m\ 51^s$
11. 11 59 57
12. 0 1 52

GREENWICH DATE.

REDUCTION OF GREENWICH DATE.

145. Def.—The Greenwich Date is the day and time (reckoned astronomically) at Greenwich corresponding to a given day and time elsewhere. It is necessary to find the Greenwich date before the information contained in the Nautical Almanac can be made available, because all the elements there tabulated are given for time at the meridian of Greenwich.

As in almost every computation of nautical astronomy we are dependent for some data upon the Nautical Almanac—and these are commonly given for Greenwich—it is generally the first step in such a computation to deduce an exact, or, at least, an approximate value of the Greenwich astronomical time. It need hardly be added that the Greenwich time should never be otherwise expressed than astronomically.

The Greenwich Date is found at once from a chronometer, the error and the rate of which is known; but it can also be found by means of the approximate time at place and the approximate longitude.

146. To find the Greenwich Date, the time at any other place and the longitude being given.

RULE LVIII.

1°. *Express the ship time astronomically* (Rule LIV, page 175).

2°. *Convert the longitude into time* (Rule LVI, page 177).

3°. **In West longitude.**—Add *longitude in time to ship time; the* **sum,** *if* less *than* 24 *hours, is the corresponding Greenwich date on the* **same** *day with the ship date; if* greater *than* 24 *hours, reject the* 24 *hours, and put the day one forward.*

4°. **In East longitude.**—*From ship astronomical time* subtract *longitude in time, if* less *than the hours, minutes, &c., of the ship date; the remainder is the corresponding Greenwich date of the same day as the ship date; if the longitude in time be* greater *than the hours, minutes, &c., of ship astronomical,* add 24 *hours to the latter, and put the day one back before the subtraction is made.*

5°. **When it is noon at the place.**—*The longitude in time, if* West, *is the Greenwich date (apparent time); but if* East, subtract *the longitude in time from* 24 *hours; the remainder is the Greenwich date (apparent time) after noon of the preceding day.*

(a) From this last it is evident that when the sun is on a meridian in *West* longitude, the Greenwich *apparent* time is precisely equal to the longitude, that is, the Greenwich apparent time is *after* the noon of the same date with the ship date, by a number of hours, &c., equal to longitude. When the sun is on a meridian in *East* longitude, the Greenwich apparent time is *before* the noon of the same date as the ship date, by a number of hours equal to the longitude in time.

NOTE.—A bad habit prevails in writing dates, of separating the month and day from the hours, minutes, and seconds. *The day of the month should always precede the minor divisions of time* which give the precise instant of the day intended.

EXAMPLES.

Ex. 1. November 9th, at 4^h 10^m P.M., apparent time at ship, longitude 32° 45′ W.: required the corresponding time at Greenwich, or the Greenwich date.

Ship date (A.T.) Nov.	9^d	4^h	10^m
Long. in time	+	2	11
Greenwich date, Nov.	9	6	21

Longitude	32°	45′
		4
6,0)13,1		0
2^h	11^m	0^s

Ex. 2. June 5th, at 7^h 15^m A.M., app. time at ship, longitude 140° 30′ E.: find corresponding Greenwich date.

Ship date (A.T.)	June	4^d	19^h	15^m
Longitude in time		—	9	22
Green. date (A.T.)	June	4	9	53

Ex. 3. January 3rd, at 8^h 12^m P.M., mean time at ship, long. 50° 45′ E.: find Greenwich date.

Ship date (M.T.)	Jan.	3^d	8^h	12^m
Longitude in time		—	3	23
Green. date (M.T.)	Jan.	3	4	49

Ex. 4. April 27th, at 5^h 35^m 45^s A.M., app. time at ship, long. 122° 13′ W.: what is corresponding Greenwich date?

Ship date (A.T.)	April	26^d	17^h	35^m	45^s
Longitude 122° 13′ W.		+	8	8	52
		26	25	44	37
		—	24		
Green. date (A.T.)	April	27	1	44	37

Ex. 5. July 20th, at 3^h 35^m 7^s P.M., mean time at ship, long. 85° 24′ E.: find corresponding Greenwich date.

Ship date (M.T.)	July	20^d	3^h	35^m	7^s
		+	24		
	or	19	27	35	7
Longitude 85° 24′ E.		—	5	41	36
Green. date (M.T.)		19	21	53	31

In Ex. 4, the added longitude advances the day of the month. (This illustrates latter part of 3° of the Rule). In Ex. 5, a day (or 24 hours) is borrowed before the subtraction is made, since the longitude in time exceeds the astronomical ship date, thus making the days of the month at Greenwich one less than at the place. (This illustrates the latter part of 4° of the Rule).

Ex. 6. 1887, January 1st, $3^h 40^m 20^s$ P.M., mean time at ship, long. 95° 7′ E.: find the Greenwich date.

Ship date (M.T.) 1887,	Jan.	1^d	3^h	40^m	20^s
Longitude 95° 7′ E.		—	6	20	28
Green. date (M.T.) 1886,	Dec.	31	21	19	52

Ex. 7. 1887, January 1st, 9^h 1^m A.M., mean time at ship, long. 107° 4′ W.: find the Greenwich date.

Ship date (M.T.) 1886,	Dec.	31^d	21^h	1^m	0^s
Longitude 107° 4′ W.		+	7	8	16
Green. date (M.T.) 1887,	Jan.	1	4	9	16

Ex. 8. Required the Greenwich date when the sun is on the meridian of a place in long. 80° 44′ E., on February 1st.

The sun being on the meridian, it is app. noon: hence

Ship date (A.T.)	Feb.	1^d	0^h	0^m	0^s
Longitude 80° 44′ E.		—	5	22	56
Green. date (A.T.)	Jan.	31	18	37	4

Ex. 9. What is the Greenwich date when the sun is on the meridian of a place in long. 155° 19′ W., on March 31st?

Ship date (A.T.)	March	31^d	0^h	0^m	0^s
Longitude 155° 19′ W.		+	10	21	16
Green. date (A.T.)	March	31	10	21	16

In Ex. 8, the hours, &c., of longitude to be subtracted are to be taken from a borrowed day, or 24 hours, thus making the day of the month at Greenwich one less than at the place. (See 5° of Rule).

EXAMPLES FOR PRACTICE.

Required the Greenwich date in each of the following examples:

1.	1887,	January 6th	at $3^h40^m16^s$ P.M.	apparent time,	long. 66° 56′ 0″ W.
2.	„	February 1st	at 5 10 50 A.M.	mean time,	long. 145 20 30 E.
3.	„	March 15th	at 9 16 22 P.M.	apparent time,	long. 17 4 0 E.
4.	„	May 15th	at 8 38 35 A.M.	apparent time,	long. 141 51 15 W.
5.	„	November 1st	at 5 0 10 P.M.	mean time,	long. 114 30 0 E.
6.	„	December 1st	at 8 0 5 A.M.	mean time,	long. 158 10 0 W.
7.	„	July 1st	at 4 0 33 P.M.	apparent time,	long. 170 55 15 E.
8.	„	September 1st	at 8 29 1 A.M.	mean time,	long. 148 47 30 W.
9.	„	July 8th	at 0 4 36 A.M.	apparent time,	long. 178 51 0 W.
10.	„	February 1st	at noon	apparent time,	long. 153 40 0 E.
11.	„	March 2nd	at noon	apparent time,	long. 1 25 0 W.
12.	1888,	January 1st	at noon	apparent time,	long. 149 10 0 E.

REDUCTION OF ELEMENTS FROM NAUTICAL ALMANAC.

147. The *Nautical Almanac** or *Astronomical Ephemeris* contains the right ascension, declination, &c., of the principal heavenly bodies for given equi-distant instants of Greenwich time; the right ascension and declination of the sun and planets, for example, being given for every day at noon ($0^h\ 0^m\ 0^s$) at Greenwich, while for the moon these elements are given for every hour. Before we can find from the *Almanac* the value of any of these quantities for a given local or ship time, we must find the corresponding Greenwich date (Rule LVIII, page 179). Where this time is exactly one of the instants for which the required quantity is put down in the Ephemeris, nothing more is necessary than to transcribe the quantity as there put down. But when, as is mostly the case, the time falls between two of the times in the Ephemeris, we must obtain the required quantity by interpolation, it being requisite to apply a correction to that taken from the *Almanac*, in order to reduce it to its value at the given instant. To facilitate this interpolation the Almanac contains the rate of change, or difference of each of the quantities in some unit of time, or, which is in general the simplest method, we may make use of certain tables computed for the purpose, called Tables of *Proportional Logarithms*.

To use the difference columns with advantage, the Greenwich time should be expressed in that unit of time for which the difference is given: thus, when the difference is for one hour, the time must be expressed in hours and decimals of an hour; when the difference is for one minute of time, the time should be expressed in minutes and decimals of a minute.

148. Simple Interpolation.—In the greater number of cases in practice, it is sufficiently exact to obtain the requisite quantities by *simple* interpolation; that is, by assuming that the difference of the quantities are proportional to the differences of the times, which is equivalent to assuming that the differences in the Ephemeris are constant. This, however, is never the case; for example, referring to the *Nautical Almanac* for 1887, the variation in declination for 1 hour for

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* The French Ephemeris, *La Connaissance de Temps*, is computed for the meridian of Paris, the German *Beliner Astronomisches Jahrbuch* for the meridian of Berlin. All these works are published annually several years in advance.

1st January is 12″·41
2nd " 13″·55
3rd " 14″·69
&c.

But the error arising from the assumption will be smaller the less the interval between the times in the Ephemeris; hence, those quantities which vary most irregularly, as the Moon's Right Ascension and Declination, are given for every hour of Greenwich time; others, as the Moon's Parallax and Semidiameters, for every twelfth hour, or for noon and midnight; others, as the Sun's Right Ascension, &c., for each noon; others, as the right ascensions and declinations of the fixed stars, for every tenth day of the year.

149. Interpolation by Second Differences.—The differences between the successive values--given in the *Nautical Almanac* as functions of time—are called the *first differences;* the differences between these successive differences are called the *second differences;* the differences of the second differences are called the *third differences*, &c. In simple interpolation we assume the function to vary uniformly; that is, we regard the first difference as constant, neglecting the second difference, which is, consequently, assumed to be zero. In interpolation by second differences we take into account the variation in the first difference, but we assume *its* variations to be constant; that is, we assume the second difference to be constant, and the third difference to be constant.

When the *Nautical Almanac* is employed we can take the second differences into account in a very simple manner. In this work, since the year 1863, the difference given for a unit of time is always the difference belonging to the instant of Greenwich time against which it stands, and it expresses, therefore, the rate at which the function is changing *at that instant.* This difference, which we may here call the first difference, varies with the Greenwich time, and (the second difference being constant) it varies uniformly, so that its value for any intermediate time may be found by simple interpolation, using the second differences as first differences. Now, in computing a correction for a given interval of Greenwich time, we should employ the *mean*, or average value, of the first difference for the interval, and this mean value, when we regard the second differences as constant, is that which belongs to the middle of the interval. Hence, to take into account the second differences, we have only to observe the very simple rule—*employ that (interpolated) value of the first difference which corresponds to the middle of the interval for which the correction is to be computed.*

TO REDUCE SUN'S DECLINATION.

150. The declination of the sun is given in the "Nautical Almanac," pages I and II of each month, for every day both for apparent and mean noon at Greenwich. The *difference of declination* for one hour *("Var. in 1 hour")* is always annexed, and is intended to facilitate the reduction of the quantities from noon to any other time. In general it is necessary to take out the required quantities for the nearest Greenwich noon to the given time, and interpolate in either direction to the given instant of Greenwich time.

Method I.—By hourly difference.*

RULE LIX.

1°. *Get a Greenwich date by means of ship time, expressed astronomically, and longitude* (see Rule LVIII, page 179), *or by means of chronometer.*

To express the Greenwich time in hours and decimals of an hour. Annex a cypher to the minutes and divide by 60, or divide the minutes by 6, *and consider the quotient as tenths* of an hour, and to this prefix the hours. For example, let it be required to express $7^h\ 18^m$ in hours and decimals of an hour. Then 6 is contained in 18 three times; to this prefix the hours (7) and we have 7·3 hours.—See Exs. 1 and 2, page 184).

2°. *Take out of* Nautical Almanac *the declination for the* nearest noon *to the given Greenwich date, noting whether the declination is* increasing—*in which case affix the sign* + *to it—or* decreasing—*when the sign* — *must be affixed—and a little to the right place the "Var. in 1 hour" found in page* I of the month in the Nautical Almanac.

(*a*) When Greenwich date is given in *apparent* time, take declination from page I of the month. but for *mean* time use page II of the month.

(*b*) The tenths of seconds (″) of declination as given in the *Nautical Almanac* may be rejected when less than five, but call them 1″ when they amount to five or above—thus, 6″·4 is put down 6″, but 42″·7 will be put down 43″; and it may be here observed, that whenever a decimal is rejected in a final result if the first decimal figure be 5, or above it, add 1 to the last figure of the result.

(*c*) When the seconds of time (in Greenwich date) are less than 30^s, they may be rejected; but if above 30^s, increase the minutes of time by 1^m; thus, Greenwich time $2^h\ 35^m\ 40^s$ would be called $2^h\ 36^m$.

3°. *Multiply the "Var. in 1 hour" by the* hours, *and fractional parts of an hour, that* **have elapsed since,** or **must elapse before** *that noon, as the case may be; the product is the correction in seconds* (″), *which, reduced to minutes and seconds, is the change of declination in the time from* noon.

4°. *Apply this correction to the declination for the* nearest noon *to the* given time, *i.e.*, *to the declination of the* same noon *as that for which the "Var. in 1 hour" has been taken as follows:—*

(a) **When the Decl. is increasing (or has + affixed).**—*The correction for the* **time elapsed since noon** *is* **additive** (see Ex. 3), *but the correction for the* **time that must elapse** *is* **subtractive** (see Ex. 4).

(b) **When the Decl. is decreasing (or has the sign — affixed.)**—*The correction for the* **time elapsed since noon** *is* **subtractive** (see Ex. 1), *but the correction for the* **time that must elapse before noon** *is* **additive** (see Ex. 2).

The result is the declination sought.

NOTE.—It must be remembered that when the declination is taken out of the *Nautical Almanac* for the noon of the *day following* that of given Green. date, the correction is applied the *contrary* way to the sign affixed.

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* This method of reducing the sun's declination is the one required to be used at the Local Marine Board Examinations.

EXAMPLES.

Ex. 1. Greenwich date, 1887, Jan. $10^d\ 6^h$; in this case take $22''\cdot42$, the "Var. for 1 hour" on the 10th, which multiplied by 6 gives the correction of the Decl. for the 10th day—to be *subtracted* because the Declination is decreasing, and we have multiplied by the number of hours that have elapsed *since* noon.

Ex. 2. Greenwich date, 1887, Jan. $10^d\ 19^h$; in this case take $23''\cdot49$, the "Var. in 1 hour" on the 11th, which multiplied by the difference between 24^h and 19^h gives the correction of the Decl. for the 11th day—to be *added* because the Decl. is *decreasing*, and we have multiplied by the number of hours that must elapse before noon of the 11th day.

Ex. 3. Greenwich date, 1887, April $2^d\ 6\frac{1}{2}^h$; in this case take $57''\cdot63$, the "Var in 1 hour" on the 2nd, which multiplied by $6\frac{1}{2}^h$, gives the correction of the declination for the 2nd April—to be *added* because the Decl. is *increasing*, and we have multiplied by $6\frac{1}{2}$ hours the time that has elapsed *since* noon, April 2nd.

Ex. 4. Greenwich date, 1887, April $2^d\ 17\frac{1}{2}^h$; in this case take $57''\cdot40$, the "Var. in 1 hour" on the 3rd, which multiplied by $6\frac{1}{2}$ (the difference between 24^h and $17\frac{1}{2}^h$) gives the correction of the Decl. for the 3rd day—to be *subtracted* because the Decl. is *increasing*, and we have multiplied by the number of hours that must elapse before noon, 3rd.

5°. *If the correction when* subtractive exceeds *the* declination *itself*, subtract *the* declination *from the* proportional part: the remainder is the declination of the contrary name.

In March when the declination changes from South to North, and in September when it changes from North to South, if the correction by being subtractive exceed the declination, subtract the declination from the correction, and call the remainder *N.* in March, but *S.* in September (see Ex. 3, following).

EXAMPLES.

Ex. 1. 1887, January 13th, at $3^h\ 54^m\ 16^s$ P.M., app. time at ship, long. 30° 4′ E.: find the sun's declination.

Ship date (A.T.) January	13^d	$3^h 54^m 16^s$		Longitude	30° 4′
Longitude (30° 4′ E.) in time	—	2 0 16	$54^m = \frac{54}{60}$.		4
Green. date (A.T.) January	13^d	$1^h 54^m\ 0^s$	60)54·0		6,0)12,0 16
	or,	$1^h\cdot9$	·9		$2^h 0^m 16^s$

Decl., page I, N.A., for January 13th, app. noon, is 21° 28′ $53''\cdot9$ S. (*decr.*)

Var. for 1^h, Jan. 13th, noon	$25''\cdot59$	Decl., noon, Jan. 13th	21° 28′ $53''\cdot9$ S. (—)
Green. time $1^h\ 54^m = 1^h\cdot9$	× 1·9	Corr. for $1^h\ 54^m$	48 ·6
	23031	Red. decl.	21 28 5 ·3 S.
	2559		
Correction	48·621		

Explanation.—Having found the Greenwich date, the sun's declination is taken from the *Nautical Almanac*, where it is found in page I of the month (the Greenwich date being in app. time), and on the same page, in column headed "Var. in 1 hour," is found the change of declination for 1 hour past noon; next observe that the declination is *decreasing*, and make a note of it. Now, since the declination changes $25''\cdot59$ in 1 hour past noon, how much does it change in the Greenwich time past noon, viz., $1^h\ 54^m$? First annex a cypher to the minutes (54^m) and divide by 60; thus 60 is contained in 540 nine times and nothing over. To this we prefix the hour and we then have the Greenwich time $1^h\ 54^m = 1^h\cdot9$ expressed in hours and decimals of an hour. Set this under the hourly diff. and then proceed as in multiplication of decimals, the resulting figures are 48621, but as we have two decimals in the multiplicand and one in the multiplier, in all three places, *three* figures are to be marked off from the right hand, leaving $48''\cdot621$ or $48''\cdot6$, the correction of decl. for $1^h\ 54^m$. This correction is to be *subtracted* from decl. at noon, because decl. is *decreasing*, and we have multiplied by the number of hours, &c., that *have elapsed* since noon.

Ex. 2. 1887, Greenwich date, March $26^d\ 14^h\ 24^m\ 18^s$, mean time: required the sun's declination.

Green. date (M.T.) March	26^d	$14^h 24^m 18^s$	$35^m\ 42^s$, or $36^m = \frac{36}{60}$)360
Subtract from		24	·6
Time *before* noon March 27th		9 35 42	
		$9^h\cdot6$	

Decl., page II, N.A., March 27th, at noon, is $2^\circ 35' 9''\cdot7$ N. (*incr.*) and Var. in $1^h = 58''\cdot70$.

Var. in $1^h =$ $58''\cdot70$
Time *before* noon $9\cdot6$

35220
52830

6,0)56,3·520

Corr. — 9′ 23·5
Decl., March 27th, noon $2^\circ 35$ 9·7 N. (+)

Red. decl. 2 25 46·2 N.

By Aliquot Parts.

Var. in $1^h =$ $58''\cdot70$
9

30^m | $\frac{1}{2}^h$ | 528·30
6 | $\frac{1}{5}$ | 29·35
| | 5·87

6,0)56,3·52

Corr. 9 23·5

Explanation.—In this example the Greenwich noon of March 27th is nearer the given time (which exceeds 12^h) than the Greenwich noon, March 26th; therefore, take out the declination from page II of the month, *Nautical Almanac* (because *mean* time), for noon March 27^d, and from page I of the month, also the "Var. in 1 hour" corresponding to this declination, viz., $58''\cdot70$. Next subtract the hours and minutes of Greenwich time from 24^h, the remainder $9^h 35^m 42^s$ or $9^h 36^m$ is the time that must elapse before noon 27th. Divide the minutes of this last by 60 to get decimals of an hour; thus 6 is contained in 36 six times, hence we have ·6, to this we prefix the hours (9) and we then have $9^h\cdot6$. Next multiply the hourly difference by this, and the resulting figures are 563520, then *three* figures marked off from the right hand leaves $563''\cdot520$, which divided by 60 gives $9' 23''\cdot5$. And since the declination at noon 27th is *increasing*, it is evident that the declination at $9^h 36^m$ *before* that noon will be *less* than at noon 27th, and the correction $9' 23''\cdot5$ is, therefore, to be *subtracted* from the decl. at that time; whence the reduced declination is $2^\circ 25' 46''\cdot2$ N.

Ex. 3. 1887, March 20th, $11^h 39^m$, app. time at Greenwich: required the sun's declination.

Green. date (A.T.), March $20^d 11^h 39^m$

$11^h\cdot65$

$39^m = \frac{6}{0}$)39·0

·65

Decl., page I, N.A., March 20th, at noon, is $0^\circ 10' 3''\cdot4$ S. (*decr.*), and var. in $1^h = 59''\cdot25$.

Var. in $1^h =$ $59''\cdot25$
11·65

29625
35550
65175

6,0)69,0·2625

Correction — 11 30·3

By Aliquot Parts.

Var. in $1^h =$ $59''\cdot25$
11

30^m | $\frac{1}{2}^h$ | 651·75
6 | $\frac{1}{5}$ | 29·62
3 | $\frac{1}{2}$ | 5·92
| | 2·96

6,0)69,0·25

— 11 30·3

March 20th, at noon $0^\circ 10'$ $3''\cdot4$ S. (—)
Correction for $11^h\cdot65$ — 11 30·3

Red. decl. 0 1 26·9 N.

In this example the correction $- 11' 30''\cdot3$, which is that due to the time elapsed since the noon for which the declination is taken out, is *subtractive*, the declination *decreasing;* but since the correction *exceeds* the declination itself, *subtract* the declination from the correction; the remainder is the reduced declination, and of a *contrary name* to that at noon. We may consider the sun moving northward, and therefore the correction may be marked N.; and since it is greater than the decl. it shows that the sun has crossed the equator, and has now North decl. Hence the difference between the decl. and the correction must be taken, and marked with the name of the greater.

(For Finding Latitude by Sun's Meridian Altitude.)

151. To find the declination of the sun at the time of its transit over a given meridian.

When the sun is on a meridian in West longitude, the Greenwich *apparent* time is precisely equal to the longitude; that is, the Greenwich apparent time is *after* the noon of the same date with the ship date by a number of hours equal to the longitude in time. **When the sun is on a meridian in** **East longitude,** the Greenwich apparent time is *before* the noon of the same date as the ship date by a number of hours equal to the longitude in time. Hence, to obtain the sun's declination for apparent noon at any meridian we have

RULE LX.

1°. *Take the declination from the* Nautical Almanac (page I of the month) *for Greenwich apparent noon of the* same date *as the* ship date.

2°. *Multiply the* "Var in 1 hour" *for the given day by the* long. in time, *the product is the* correction *in seconds* (″), *which convert into minutes* (′) *and seconds* (″), which is applied as follows:—

3°. (a) *If in* West *longitude and declination increasing* **add** *correction to the declination at noon* (see Ex. 1); *but if declination is decreasing the correction is* **subtracted.**

(b) *If in* East *longitude and declination is increasing* **subtract** *the correction from the declination* (see Ex. 2); *but if the declination is decreasing* **add** *the correction,* and the result will be the correct declination (see Ex. 3).

Examples.

Ex. 1. 1887, June 1st, the sun on the meridian, long. 75° W.: required the sun's decl.

Long. 75° W.
4
6,0)30,0
5^h

The longitude being 5^h West, the Greenwich A.T. is 5^h *after* the noon of June 1st—the same date as the ship date. The decl. is taken out of the *Nautical Almanac*, page I of the month, for June 1st; also take out at the same time the var. in 1^h; the work will stand thus:—

Sun's decl., page I, N.A.		Var. in 1^h, page I, N.A	
June 1st, at noon	22° 3′ 9″N. +	June 1st, noon	20″·46
Correction	+ 1 42		5
Red. decl.	22 4 51 N.		6,0)10,2·30
		Correction	1 42

As the decl. is *increasing*, the decl. at 5^h *after* noon will evidently be greater than that for noon.

Ex. 2. In the last question suppose the longitude to be 75° E.

The longitude being 5^h E., the Green. A.T. is 5^h *before* the noon of June 1st—the same date as the ship date. The decl. is taken out of the *Nautical Almanac*, page I of the month, for June 1st; also the var. in 1^h, and the work is as follows:—

Sun's decl., page I, N.A.			
June 1st, at noon	22° 3′ 9″N. +	Var. in 1^h =	20″·46
Correction	— 1 42		5
Red. decl.	22 1 27 N.		6,0)10,2·30
			1 42

As the decl. is *increasing* it is evident the decl. at 5^h *before* noon will be less than that for noon.

Ex. 3. 1887, September 10th, the sun on the meridian, long. 100° 35′ E.: required the sun's declination.

Longitude 100° 35′ E.
4
6,0)40,2 20
$6^h 42^m 20^s$

The longitude being $6^h 42^m 20^s$ East, the Green. A.T. is $6^h 42^m$ *before* the noon of September 10th—the same date as the ship date. The decl. is taken out of the *Nautical Almanac*, page I of the month, for Sept. 10th; also take out at the same time the hourly diff.; the work will stand thus:—

Sun's decl., page I, N.A.
Sept. 10th, noon 4° 58′ 9″ N. (—)
Corr. for $6^h 42^m$ + 6 21
Red. decl. 5 4 30 N.

As the declination is *decreasing*, the declination at $6^h 42^m$ *before* noon will evidently be greater than that for noon.

Var. in 1^h, page I, N.A.
Sept. 10th, noon 56″·88
Time from noon 10th, $6^h 42^m$ = 6·7
6,0)38,1·096
6 21

152. Degree of Dependence.—The sun's declination changes nearly 1′ an hour, or 1″ in 1^m, in March and September; hence to insure it to 1″ in the extreme case, the Greenwich date must be true to 1^m.

EXAMPLES FOR PRACTICE.

Required the sun's declination in each of the following examples:—

[These are preparatory to working Amplitudes, Azimuths, &c.]

1.	1887,	January 5th,	$6^h 23^m 32^s$ A.M.	app. time at ship	long. 108° 7′ W.
2.	,,	February 2nd,	3 9 0 P.M.	app. time at ship	long. 52 45 W.
3.	,,	March 31st,	6 2 12 P.M.	app. time at ship	long. 156 3 E.
4.	,,	May 16th,	9 17 20 A.M.	mean time at ship	long. 45 43 W.
5.	,,	June 10th,	8 45 0 P.M.	app. time at ship	long. 129 30 E.
6.	,,	October 1st,	6 11 50 A.M.	mean time at ship	long. 68 15 W.
7.	,,	December 16th,	4 35 32 A.M.	app. time at ship	long. 4 8 E.
8.	,,	November 14th,	6 45 8 P.M.	mean time at ship	long. 100 2 E.

In each of the following examples it is required to find the sun's declination when the sun is on the meridian (at apparent noon):—

9.	1887, Jan. 19th,	long.	86° 57′ W.	13.	1887, Sept. 23rd,	long.	156° 0′ E.
10.	,, Feb. 16th,	long.	72 59 E.	14.	,, Oct. 1st,	long.	170 58 E.
11.	,, Mar. 20th,	long.	168 3 W.	15.	1888, Jan. 1st,	long.	156 48 E.
12.	,, July 28th,	long.	2 0 W.	16.	1887, Sept. 23rd,	long.	26 15 E.

153. To find the Polar Distance of a celestial object, proceed according to the following rule (see Definition, page 161):—

RULE LXI.

When the latitude *of the place, and* declination *of the object, are of the same name* subtract the declination *from* 90°; *but when the* latitude *and* declination *are of* contrary *names,* add the declination *to* 90°; the result in either case is the polar distance.

When the latitude is 0, the declination, either *added* to or *taken* from 90°, is the polar distance.

Examples.

Lat.	Declination.	Polar Distance.
N.	8°12′ 18″ S.	98°12′ 18″
N.	22 30 0 N.	67 30 0
S.	2 31 15 S.	87 28 45
N.	30 23 15 S.	120 23 15
S.	7 22 32 N.	97 22 32
S.	26 42 12 S.	63 17 48
0	12 48 2 N.	102 48 2 or 77 11 58

154. To Reduce Equation of Time to Greenwich Date.—The method of correcting the equation of time for the Greenwich date is similar to that for correcting the sun's declination, and the "Variation in 1 hour" may be used for the purpose (see Defs., pp. 168-169).

RULE LXII.

1°. *Get a Greenwich date, as before.*

Note.—The time by chronometer when error and rate are applied to it, gives Mean Time at Greenwich.

2°. *Take out of* Nautical Almanac (page II of the month) *the Equation of Time for the noon of* Greenwich Date, *and mark it* additive *or* subtractive, *according to the heading of Equation of Time* at the top of the column *in* **page I** of the month, *when it is required to turn apparent time into mean time; but according to the heading in* **page II** *if to convert mean time into apparent; also note whether it is increasing—when affix the sign +; or* decreasing—*affixing the sign —; at the same time take from the column in* page I *the "Var. in 1 hour."**

Note.—Since the Equation of Time is used either for turning mean time into apparent time, or for turning apparent into mean time, it will be necessary to attend to the precept given at the head of the column of Equation of Time. When a line —— is placed at the heading of a column, a similar one comes between two days in the column itself; in which case it means that all the Equations of Time above the line are to be applied according to the directions *above* the line in the heading, and all the Equations of Time below the line must be applied as directed *below* the line in the heading. The line —— is placed between these two days in which Equation of Time changes from addition to subtraction, and *vice versa*, showing that at some particular instant in the interval the Equation of Time is $0^m\ 0^s$. Thus, in April, 1887, page I of the month, a black line is placed between the Eq. T. for the 15th and that for the 16th, indicating that a change of precept occurs between those days. The Equations above the line, page I, have to be added, those below have to be subtracted.

3°. *Multiply the "Var. in 1 hour" by the hours of* Greenwich time, *and when great precision is necessary, by the fractional parts of an hour also. The result is the correction to be applied to the equation of time taken from the* Nautical Almanac, *and is to be* added *when equation of time is* increasing, *but* subtracted *when equation of time is* decreasing; the result is the Equation of Time sought.

---

* As the equation of time is not a uniformly varying quantity, it is not quite accurate to compute its correction as above, by multiplying the given hourly difference by the number of hours in the Greenwich time; for that process assumes that this hourly difference is the same for each hour. The variations in the hourly difference are, however, so small that it is only when extreme precision is required that recourse must be had to the more exact method of interpolation for second differences.

Note.—We may, as in reducing the declination (see preceding Rule LIX), take the Eq. T. and "Var. in 1^h" from the *Nautical Almanac* for the *nearest* noon to the Greenwich time, and multiplying the "Var. in 1^h" by the time that must elapse before noon; the correction thus obtained must be applied to the Eq. of T. taken out of *Nautical Almanac* in a *contrary* way to that directed above, that is to say, when correcting *backwards* the rule is Eq. T. *increasing*, subtract—Eq. T. *decreasing*, add. (See Exs. 3, 4, and 5).

(a) *When the correction being subtractive,* exceeds *the equation of time itself,* subtract *the equation of time from the correction; the remainder is the reduced equation of time sought—and it is to be* subtracted *from apparent (or mean) time, as the case may be, when equation of time at noon is directed to be* added, *but* added *to apparent (or mean) time when equation of time at noon is directed to be* subtracted; i.e., *the Equation has to be* applied *to* A.T. according *to the* precept *for* the day following the given day.

EXAMPLES.

Ex. 1. 1887, January 29th, $6^h\ 53^m\ 49^s$ mean time at Greenwich: find Equation of time to be applied to apparent time in working the chronometer.

Eq. of Time, page II, N.A.		Hourly Diff., page I, N.A.	
Jan. 29th, *add*	$13^m 21^s{\cdot}7$ (+)	Jan. 29th, at noon	$0^s{\cdot}435$
Corr. for $6^h{\cdot}9$	+ 3·0	$6^h\ 54^m$ is $6^h{\cdot}9$	6·9
Red. Eq. Time	13 24·7		3915
			2610
(To be *added* to app. time).		Correction	3·0015
		or,	$3^s{\cdot}0$

Explanation.—In working this example, the Greenwich date being given in mean time, take the Eq. of time from page II of the month in the *Nautical Almanac*, and mark it *additive* to apparent time, as directed at the top of the column in page I (the Eq. T. being required to convert apparent into mean time), also note that the Eq. T. is *increasing*. Next, the "Var. in 1^h" is taken from the column in page I of the month. The Greenwich time being $6^h\ 54^m$ or $6^h{\cdot}9$; hourly difference is multiplied by 6·9 giving the product 30015, and since there are three decimal figures in H.D. (435) and one in Greenwich time (·9) in all four, *four* decimal places are marked off from the right hand of the product, the result 3·0015 or $3^s{\cdot}0$ is the correction to be applied to the Eq. of time at noon, and is to be *added* to it because it is that due to time *elapsed since* noon while the Eq. T. is *increasing*.

Ex. 2. 1887, September 29th, $13^h\ 45^m$ mean time at Greenwich: find the Equation of time to be applied to mean time to get apparent time in working the Time Azimuth or Reduction to Meridian.

Eq. T., page II, N.A.		Var. in 1^h, page I, N.A.	
Sept. 29th, noon, *add*	$9^m 38^s{\cdot}2$ (+)	Sept. 29th,	$0^s{\cdot}824$*
Corr. for $13^h\ 45^m$	+ 11·3	Green. time $13^h\ 45^m$ =	13·75
Red. Eq. T.	9 49·5	* Multiply 13·75 by ·824, thereby saving a line of multiplication.	5500
(To be *added* to M.T.)			2750
			11000
			11·33000
		or,	$11^s{\cdot}3$

In this instance it is required to turn mean time into apparent time, therefore the Red. Eq. T. is to be applied to mean time according to precept at head of the column in page II of the month in *Nautical Almanac*.

Or, proceeding according to note to 3° in Rule, we may take out the Eq. T. from the *Nautical Almanac* for the *nearest* noon to Greenwich time, viz., noon, Sept. 30th, and multiply the corresponding "Var. in 1^h" by the time that *must elapse* before noon, viz., ($24^h - 13^h\ 45^m =$) $10^h\ 15^m$; the result is the correction to be applied to the Eq. T. taken out of *Nautical Almanac* in a *contrary* way to that above. The work will stand thus:—

Green. date,	Sept. $29^d\ 13^h 45^m$
Subtract from	24
Time from noon,	Sept. 30^d 10 15

Eq. T., page II, N.A.

Sept. 30th, noon, *add*	$9^m 57^s{\cdot}9$ (+)
Corr. for $10\frac{1}{4}^h$	— 8·3
Red. Eq. T.	9 49·6

(To be *added* to M.T.)

Var. 1^h, page I, N.A.

Sept. 30th, at noon	$0^s{\cdot}813$
Time *before* noon	$10\frac{1}{4}$
Corr. for 10^h	8130
Corr. for $\frac{1}{4}^h$	203
Corr. for $10\frac{1}{4}^h$	8·333
or,	8·3

The Eq. T. would, in this case, be *less* $10\frac{1}{4}^h$ *before* noon than what it is at noon; the correction is therefore subtracted from the Eq. T. at noon.

Ex. 3. 1887, December 24th, $12^h\ 54^m$ mean time at Greenwich: find the Equation of time to be applied to apparent time in working the chronometer.

Green. date (M.T.), Dec. $24^d\ 12^h\ 54^m$ = Dec. $24^d\ 12^h$ 9.

Eq. T., page II, N.A.

Dec. 24th, noon, *subt.*	$0^m 14^s{\cdot}9$ (—)
Corr. for $12^h{\cdot}9$	— 16·1
Red. Eq. T.	0 1·2

(To be *added* to A.T.)

Var. in 1^h, page I, N.A.

Dec. 24th, noon	$1^s{\cdot}246$
Green. time	12·9
	11214
	14952
Corr.	16·0734
or,	$16^s{\cdot}1$

In this case the correction is *subtractive*, and exceeds in amount the Eq. T. at noon, therefore the Eq. T. is taken from the correction, and the remainder is the reduced Eq. T. to be *added* to A.T., according to the precept for the day following the given day—a change of precept occurring between Dec. 24th and Dec. 25th —which change is shown by means of a black line between the equations for the two named days.

Ex. 4. 1887, June 14th, $22^h\ 25^m\ 21^s$ mean time at Greenwich: find Equation of time to be applied to mean time to deduce apparent time.

Green. date,	June $14^d\ 22^h 25^m$
or,	$22^h{\cdot}4$

Eq. T., page II, N.A.

June 14th, noon, *subt.*	$0^m\ 5^s{\cdot}7$ (—)
Corr. for $22^h\ 25^m$	11·7
Red. Eq. T.	0 6·0

(To be *added* to A.T.)

Var. in 1^h, page I, N.A.

June 14th, noon	$0^s{\cdot}524$
Time *past* noon	22·4
	2096
	1048
	1048
Corr.	11·7376
or,	$11^s{\cdot}7$

In this case the correction is *subtractive* and exceeds the equation itself, therefore the equation is *subtracted* from the correction, and the difference is the reduced Eq. T., which is to be applied to mean time according to the precept on page II for the day following the given day.

By using the Eq. T. corresponding to the *nearest* Greenwich noon, viz., that for June 15th, the work will stand thus:—

Green. date,	June $14^d\ 22^h 25^m$
Subtract from	24
Time from noon,	June 15^d 1 35
or,	$1^h{\cdot}6$

Eq. T., page II, N.A.

June 15th, at noon, *add*	$0^m\ 7^s{\cdot}0$ (+)
Correction for $1^h{\cdot}6$	0·8
Red. Eq. T.	0 6·2

(To be *added* to A.T.)

Var. in 1^h, page I, N.A.

June 15th, at noon	$0^s{\cdot}530$
Time from noon, 15th,	1·6
	318
	53
Corr.	·848
or,	$0^s{\cdot}8$

Ex. 5. 1887, August 31st, $19^h\ 14^m\ 24^s$, mean time at Greenwich: find Equation of time to be applied to apparent time.

Eq. of Time, page II, N.A.		Hourly Diff., page I, N.A.	
Aug. 31st, at noon, *add*	$0^m 14^s\!\cdot\!85$ (—)	Aug. 31st, noon	$0^s\!\cdot\!772$
Corr. for $19^h\ 14^m$	— 14·86	$19^h\ 14^m$	= $19\frac{1}{4}$
Red. Eq. T.	0 0·0		6948
			772
			193
		Correction	14·861
		or,	$14^s\!\cdot\!86$

Examples for Practice.

In each of the following examples it is required to find the equation of time corresponding to the given Greenwich date, and how it is to be applied in the first six examples to Apparent Time to deduce Mean Time, and in the remaining examples, how it is to be applied to Mean Time to turn it into Apparent Time.

1. 1887, Jan. 5th, at $4^h 33^m\ 0^s$ M.T.
2. „ Feb. 18th, at 8 20 0 M.T.
3. „ April 14th, at 22 30 10 M.T.
4. „ May 19th, at 6 56 0 M.T.
5. „ June 14th, at 11 49 50 M.T.
6. „ Aug. 31st, at 21 14 40 M.T.
7. 1887, June 14th, at $12^h 52^m\ 0^s$ M.T.
8. „ Aug. 31st, at 15 54 0 M.T.
9. „ May 14th, at 9 36 0 M.T.
10. „ Nov. 14th, at 21 35 0 M.T.
11. „ Dec. 24th, at 18 2 54 M.T.
12. „ Dec. 24th, at 7 18 0 M.T.

CORRECTION OF THE OBSERVED ALTITUDE.

155. The corrections necessary to reduce an altitude observed from the sea-horizon with a quadrant or sextant, &c., to the *true* altitude, consist of the index correction, the dip, the correction of altitude, or the joint effect of refraction and parallax, and, in certain cases, of the semidiameter. (See Defs., pp. 164-166).

The altitudes of heavenly bodies are observed from the deck of a ship at sea, with the sextant, for the purpose of finding latitude, longitude, &c. Such an altitude is called the "*observed altitude.*" There are certain instrumental and circumstantial sources of error by which this is affected:—(*a*) The sextant (supposed otherwise to be in adjustment) may have an index error; (*b*) The eye of the observer being elevated above the surface of the sea, the horizon will appear to be depressed, and the consequent altitude in reality too great; and (*c*) One of the limbs of the body may be observed instead of its centre. When the correction for these errors and method of observing are applied—"the index correction," "correction" for dip, and "semidiameter,"—the observed is reduced to the *apparent altitude.* But again, for the sake of comparison and computation, all observations must be transformed into what they would have been had the bodies been viewed through a uniform medium, and from one common centre—the centre of the earth. The altitude supposed to be so taken is called the "*true altitude;*" it may be deduced from the apparent altitude by applying the corrections called "corrections for refraction" (Table IV, Norie, or XXXI, Raper), and "correction for parallax" (Table VI, Norie, or XXXIV, Raper), which, however, are sometimes given in tables combined under the names "correction of altitude" (Table XVIII, Norie). (*a'*) "Correction for refraction;" when a body is viewed through the atmosphere, refraction will cause the apparent to be greater than the true altitude; hence the correction for refraction is subtractive in finding the true from the apparent altitude. (*b'*) "Correction for parallax;" the position of the observer on the surface, especially for near bodies, will cause the apparent to be less than the true altitude; hence the correction for parallax is additive in finding the true from the apparent altitude.

TO CORRECT THE SUN'S ALTITUDE.

RULE LXIII.

1°. *Correct the observed altitude of the sun for index error, if any.*

2°. Subtract *the dip answering to height of eye* (Table V, Norie, and Table XXX, Raper); *the remainder is the apparent altitude of the limb observed.*

3°. Subtract *the refraction* (Table IV, Norie, and XXXI, Raper), add *the parallax* (Table VI, Norie, and XXXIV, Raper); *or take out the "correction in altitude of sun"* (Table XVIII, Norie), *and subtract it; the remainder is the* true *altitude of the observed limb.*

4°. *Take from* page II *of the month in the* Nautical Almanac *the* sun's *semidiameter,* adding *it when the sun's* lower limb (L.L.) *is observed, but subtracting it when the sun's* upper limb (U.L.) *is observed;* the result thus obtained is the true altitude of the sun's centre.

Table IX, Norie, and Table 38, Raper, contain the gross correction of altitude, or the corrections for dip, refraction, sun's semidiameter, and parallax—exclusive of index error—which are sometimes used in solving questions in nautical astronomy when great precision is not necessary.

Examples.

Ex. 1. 1887, January 6th, the observed altitude sun's L.L. 39° 8′ 30″, index correction + 33″, height of eye 19 feet: required the true altitude.

Raper.

Obs. alt. sun's L.L.	39° 8′ 30″
Index correction	+ 33
	39 9 3
Dip (Table 30)	— 4 15
App. alt. sun's L.L.	39 4 48
Ref. (Table 31) —Par. (Table 34)	— 1 5
True alt. sun's L.L.	39 3 43
Semidiameter	+ 16 18
True altitude	39 20 1

Norie.

Obs. alt. sun's L.L.	39° 8′ 30″
Index correction	+ 33
	39 9 3
Dip (Table 5)	— 4 11
App. alt. sun's L.L.	39 4 52
Corr. alt. (Table 18)	— 1 3
True alt. sun's L.L.	39 3 49
Semidiameter	+ 16 18
True altitude	39 20 7

Ex. 2. 1887, June 18th, the observed altitude sun's L L. 71° 19′ 20″, index correction + 3′ 46″, height of eye 18 feet: required the true altitude.

Obs. alt. sun's L.L.	71° 19′ 20″
Index correction	+ 3 46
	71 23 6
Dip (Table 30)	— 4 10
	71 18 56
Ref. — 0′ 20″ Par. + 3	— 17
	71 18 39
Semid., p. II, N.A.	+ 15 46
True altitude	71 34 25

Obs. alt. sun's L.L.	71° 19′ 20″
Index correction	+ 3 46
	71 23 6
Dip (Table 5)	— 4 4
	71 19 2
Corr. of alt. (Table 18)	— 17
	71 18 45
Semidiameter	+ 15 46
True altitude	71 34 31

Ex. 3. 1887, August 8th, observed altitude sun's U.L. 12° 52′ 30″, index correction + 3′ 10″, height of eye 17 feet.

Obs. alt. sun's U.L.	12°52′ 30″
Index correction	+ 3 10
	12 55 40
Dip 17 feet	— 4 5
	12 51 35
Ref. — 4′ 11″ Par. + 8	— 4 3
	12 47 32
Semidiameter	— 15 49
True altitude	12 31 43

Obs. alt. sun's U.L.	12°52′ 30″
Index correction	+ 3 10
	12 55 40
Dip 17 feet	— 3 57
	12 51 43
Correction altitude	— 3 57
	12 47 46
Semidiameter	— 15 49
True altitude	12 31 57

Examples for Practice.

1.	1887,	Jan. 29th,	Obs. alt. sun's L.L.	17°44′ 30″	Index corr.	— 1′ 25″	Eye 16	feet.
2.	„	Feb. 18th,	„	48 4 10	„	+ 0 55	„ 12	„
3.	„	April 20th,	„	76 3 0	„	— 1 27	„ 10	„
4.	„	May 8th,	„	58 38 20	„	— 1 10	„ 18	„
5.	„	July 16th,	„	65 1 0	„	+ 0 17	„ 14	„
6.	„	Aug. 7th,	„	85 13 20	„	— 2 10	„ 18	„
7.	„	Sept. 2nd,	„	U.L. 28 16 20	„	— 4 8	„ 10	„
8.	„	Oct. 11th,	„	U.L. 67 44 0	„	— 1 38	„ 15	„

TO FIND THE LATITUDE BY A MERIDIAN ALTITUDE OF THE SUN.

RULE LXIV.

1°. *With the ship's date and longitude in time, find the Greenwich date* in apparent time (Rule LVIII, 5°, page 179).

2°. *Take the sun's declination from* Nautical Almanac, (page I of the month), *and correct it for the Greenwich date* (Rule LIX, page 183).

Instead of proceeding according to 1° and 2° the declination may be found thus:—1. Take the sun's declination from the *Nautical Almanac*, for apparent noon, page I; and also the corresponding hourly difference. 2. Multiply the hourly diff. by long. in time, expressed in hours and decimals of an hour. 3. When the declination is *increasing* the correction is to be *added* in *West*, but *subtracted* in *East* longitude; but when the declination is *decreasing*, *subtract* in *West* but *add* in *East* longitude. (See Rule LX, page 186.)

3°. *Correct the observed altitude for index error, dip, semidiameter, and refraction and parallax, and thus get the true altitude* (Rule LXIII, page 192); *subtract true altitude from* 90°: *the result will be the true zenith distance.**

4°. *Call the zenith distance* N. *when the observer is North of sun, or when the sun bears South; call zenith distance* S. *when the observer is South of sun, or when it bears North.*

5°. Add *together the declination and zenith distance, when they have the* same *name* (see Exs. 1, 3, 6, and 7); *but take the* difference *if their names be* unlike (see Exs. 2, 4, 8, 9, 10, and 11); *the latitude is* N. *or* S. *as the greater is.*

6°. *When the declination is* 0°, *the zenith distance is the latitude, and of the* same *name as the* zenith distance (see Exs. 5 and 12); and *when the zenith distance is* 0°, *the declination is the latitude, which is of the* same *name as the* declination (see Ex. 13).

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* When *true* altitude exceeds 90°, subtract 90° from it.

EXAMPLES.

Ex. 1. 1887, January 15th, in longitude 72° 42′ W., the observed meridian altitude of the sun's L.L. (lower limb) was 59° 42′ 10″, bearing North; index error + 2′ 10″, height of eye 14 feet: required the latitude.

The observation was made when the sun was on the meridian, that is, at apparent noon; the date, therefore, at the place of observation is January 15th, $0^h\ 0^m\ 0^s$. But the meridian of the place of observation is 72° 42′ W. of meridian of Greenwich, and therefore the sun is 72° 42′ W. of meridian of Greenwich; or, in time $4^h\ 50^m\ 48^s$, since 72° 42′ is equivalent to $4^h\ 50^m\ 48^s$ (see below). It is, therefore, $4^h\ 50^m\ 48^s$ *past* apparent noon at Greenwich, and the Greenwich date is found by *adding* $4^h\ 50^m\ 48^s$ to the time of apparent noon at ship, January 15th, thus:—

Ship date, January	$15^d\ 0^h\ 0^m\ 0^s$	72° 42′
Longitude 72° 42′ W.	+ 4 50 48	4
Greenwich date, Jan.	15 4 50 48	$4^h 50^m 48^s$

With this date the sun's declination must be taken out of *Nautical Almanac*, where it will be found in page I for January. It may be reduced to Greenwich date by means of the Tables, or by "hourly diff.," thus:—

Decl., page I, N.A.	
Jan. 15th, at noon	21° 7′ 36″ S. (—)
Corr. for $4^h\ 51^m$	2 14
Red. decl.	21 5 22 S.

Hourly diff., page I, N.A.	
Jan. 15th	— 27″·64
$4^h\ 51^m = 4^h{\cdot}85$	× 4·85
	13820
	22112
	11056
	6,0)13,4·0540
Correction	— 2 14·1

In working this example the H. diff. for the *noon* of the day is taken. We divide the minutes of Greenwich time by 6; thus, 6 is contained in 51 eight times and three over, 6 is contained in 30 (the remainder 3 with a 0 added) five times; hence we have the decimal ·85, to this we prefix the hours (4), and we then have $4^h{\cdot}85$ to multiply by. As the Greenwich date wants 10^m of 5 hours, we might have multiplied the hourly diff. by 5, and deducted one-sixth of hourly diff. from the product.

Raper.

Obs. alt. sun's L.L.	59° 42′ 10″ N.
Index error	+ 2 10
	59 44 20
Dip (Table 30)	— 3 40
App. alt. sun's L.L.	59 40 40
Refraction (Table 31)	— 34
	59 40 6
Parallax (Table 34)	+ 4
True alt. sun's L.L.	59 40 10
Semidiameter	+ 16 18
True altitude	59 56 28
	90 0 0
Zenith distance	30 3 32 S.
Declination	21 5 22 S.
Latitude	51 8 54 S.

Norie.

Obs. alt. sun's L.L.	59° 42′ 10″ N.
Index error	+ 2 10
	59 44 20
Dip (Table 5)	— 3 36
	59 40 44
Corr. alt. (Table 18)	— 29
	59 40 15
Semidiameter	+ 16 18
True altitude	59 56 33
	90 0 0
Zenith distance	30 3 27 S.
Declination	21 5 22 S.
Latitude	51 8 49

The meridian zenith distance and declination are added, because they are of the *same* name. (This is according to No. 5° of the Rule).

Ex. 2. 1887, February 3rd, in longitude 139° 42′ E., the observed meridian altitude of the sun's L.L. 56° 56′ 56″, bearing South; index correction — 3′ 4″; height of eye 14 feet.

The observation was made when the sun was on the meridian, that is, at apparent noon; the date, therefore, at the place of observation is Feb. $3^d\ 0^h\ 0^m\ 0^s$. But the meridian of the place of observation is 139° 42′ E. of meridian of Greenwich, and, therefore, the sun is 139° 42′ E. of meridian of Greenwich; or, in time, $9^h\ 18^m\ 48^s$—since 139° 42′ is equivalent to $9^h\ 18^m\ 48^s$ (see below). It is, therefore, $9^h\ 18^m\ 48^s$ *before* apparent noon at Greenwich, and the Greenwich date is found by *subtracting* $9^h\ 18^m\ 48^s$ from the time of apparent noon at ship, thus:—

Ship date, February	$3^d\ 0^h\ 0^m\ 0^s$	139° 42′ E.
Longitude 139° 42′ E.	— 9 18 48	4
Green. date, February	2 14 41 12	6,0)55,8 48
		$9^h 18^m 48^s$

We take out of the *Nautical Almanac*, page I of the month, the decl. and "var. in 1^h" for the nearest noon to the given Greenwich date, viz., for noon, Feb. 3rd; and since the long. is $9^h\ 18^m\ 48^s$, the Greenwich date is that amount *before* the noon of Feb. 3rd, we, therefore, multiply the "var. in 1^h" 44·16 by 9^h·3; the resulting figures are 410·688, or 6′ 51″. The decl. at noon, *decreasing*, will evidently be *more* at that instant than $9^h\ 19^m$ *before* noon; therefore, the correction is 6′ 51″ to be *added* (see Rule, 2°, note).

Ship date, February	$3^d\ 0^h\ 0^m\ 0^s$
Long. 139° 42′ E.	— 9 18 48
Green. date, February	2 14 41 12
Time *before* noon, Feb.	3 9 19

Decl., page I, N.A., Feb. 3rd = 16° 31′ 8″ S., *decr.* Hourly diff. 44″·16.

Hourly diff., Feb. 3rd, noon	44″·16
Time *before* noon $9^h\ 19^m$	× 9·3
	13248
	39744
	6,0)41,0·688
Correction	+ 6 51
Decl., noon, Feb. 3rd	16 31 8 S.—
Red. decl.	16 37 59 S.

By *Raper*: Index corr. — 3′ 4″; dip — 3′ 40″; refr. — 0′ 38″; par. + 4′; semid. + 16′ 16″; true alt. 57° 5′ 54″; latitude 16° 16′ 7″ N.

Norie.

Obs. alt. sun's L.L.	56° 56′ 56″ S.
Index correction	— 3 4
	56 53 52
Dip (Table 5, *Norie*)	— 3 36
App. alt. sun's L.L.	56 50 16
Corr. alt. (Table 18)	— 0 32
True alt. sun's L.L.	56 49 44
Semidiameter	+ 16 16
True alttitude	57 6 0
	90 0 0
Zenith distance	32 54 0 N.
Declination	16 37 59 S.
Latitude	16 16 1 N.

The difference of zenith distance and declination is taken because they are of *contrary* names, the lat. taking the name of the greater. (See No. 5° of Rule).

Ex. 3. 1887, March 20th, longitude 178° 35′ W., observed meridian altitude of the sun's L.L. 52° 52′ 50″, bearing South; index correction + 1′ 5″; height of eye 12 feet.

Ship date, March	$20^d\ 0^h\ 0^m\ 0^s$
Long. in time	+ 11 54 20
Green. date, March	20 11 54 20
or,	11^h·9

Hourly diff., noon, 20th	59″·25
T. from noon, 20th, $11^h\ 54^m$	× 11·9
	53325
	65175
	6,0)70,5·075
Correction	— 11′ 45″

Decl., March 20th, noon	0° 10′ 3″ S., *decr.*
Correction	— 11 45
Red. decl.	0 1 42 N.

By *Raper*: Dip — 3′ 20″; refr. — 0′ 44″; par. + 5″; semid. + 16′ 5″. True alt. 53° 6′ 1″, and latitude 36° 55′ 41″ N.

Obs. alt. sun's L.L.	52° 52′ 50″ S.
Index correction	+ 1 5
	52 53 55
Dip *(Norie)*	— 3 19
App. alt. sun's L.L.	52 50 36
Corr. of alt.	— 38
True alt. sun's L.L.	52 49 58
Semidiameter	+ 16 5
True altitude	53 6 3
	90 0 0
Zenith distance	36 53 57 N.
Declination	0 1 42 N.
Latitude	36 55 39 N.

The mer. zen. dist. and decl. being of the *same* name their *sum* is taken for the latitude (see No. 5° of Rule).

Ex. 4. 1887, July 13th, longitude 100° W., observed meridian altitude sun's L.L. 68° 2′ 0″, bearing North, index correction — 2′ 16″, height of eye 17 feet.

Ship date (A.T.) July	13ᵈ 0ʰ 0ᵐ 0ˢ
Long. in time	+ 6 40 0
Green. date, July	13ᵈ 6 40 0

Decl., p. I, N.A., July 13th, 21° 51′ 12″ N. —

Hourly diff., July 13th, noon			21″·71
Time from noon 6ʰ 40ᵐ			6
			130·26
	30ᵐ	½ʰ	10·85
	10	⅓	3·61
			6,0)14,4·72
Correction			— 2 25
Decl., noon, 13th			21 51 12 N.
Red. decl.			21 48 47 N.

By *Raper:* Index corr. — 2′ 16″; dip — 4′ 5″; corr. alt. — 21″; semid. + 15′ 46″; true alt. 68° 11′ 4″; latitude 0° 0′ 9″ S.

North.

Obs. alt. sun's L.L.	68° 2′ 0″ N.
Index correction	— 2 16
	67 59 44
Dip (Table 5)	— 3 57
	67 55 47
Corr. alt. (Table 18)	— 20
	67 55 27
Semidiameter (N.A.)	+ 15 46
True alt.	68 11 13
	90 0 0
Zenith distance	21 48 47 S.
Declination	21 48 47 N.
Latitude	0 0 0

The ship is on the equator.

When the zenith distance and declination are numerically equal, and of contrary names, the ship is on the equator.

Ex. 5. 1887, September 23rd, long. 44° 24′ E., observed meridian altitude of sun's L.L. 40° 9′, bearing North, index correction + 20″, height of eye 18 feet.

Green. date (A.T.) Sept. 22nd	21ʰ 2ᵐ 24ˢ
Time from noon, Sept. 23rd	2 57 36
	2·96

Decl., page I, N.A., Sept. 23rd, at noon, is 0° 2′ 53″ S., *increasing*, hourly diff. 58″·49.

H. diff., Sept. 23rd, noon	58″·49
Time from noon, Sept. 23rd	2·96
	35094
	52641
	11698
	6,0)17,3·1304
	— 2 53
Decl., Sept. 23rd	0 2 53 S. *incr.*
Red. decl.	0 0 0

The decl. is taken out for the *nearest* noon to Green. date, viz., Sept. 23rd at noon, and corrected for the interval between it and the Green. time, which is equal in amount to the longitude in time, viz., 2ʰ 57ᵐ 36ˢ (= 2ʰ·96). We might have found the correction for 3ʰ and taken from this result the change for 2ᵐ, or one-thirtieth of the hourly difference.

Obs. alt. sun's L.L.	40° 9′ 0″ N.
Index correction	+ 20
	40 9 20
Dip 18 feet (Table 5)	— 4 4
	40 5 16
Corr. alt. (Table 18)	— 1 1
	40 4 15
Semidiameter, N.A.	+ 15 59
True altitude	40 20 14
	90 0 0
Zenith distance	49 39 46 S.
Declination	0 0 0
Latitude	49 39 46 S.

By *Raper:* Index correction + 20″; dip — 4′ 10″; refr. — 1′ 9″; par. + 7″; semid. + 15′ 59″; true alt. 40° 20′ 7″; latitude 49° 39′ 53″ S.

The foregoing examples show the form and method of computing the Latitude from a Meridian Altitude of the Sun, and the following examples illustrate every possible variety of form under which the latter part of the problem can occur.

EXAMPLES.

Exs. 6 and 7. Zenith Distance and Declination of *same* name, N. or S.

True mer. alt.	40° 16′ 8″ S.	True mer. alt.	49° 56′ 31″ N.
	90 0 0		90 0 0
Mer. zen. dist.	49 43 52 N.	Zen. dist.	40 3 29 S.
Declination	11 14 40 N.	Declination	12 3 10 S.
Latitude	60 58 32 N.	*Latitude*	52 6 39 S.

Exs. 8 and 9. Zen Dist. and Decl. of *different* names, and Zen. Dist. greater than Decl., the Lat. is of same name as Zen. Dist.

True alt.	32° 54′ 14″ S.	True alt.	59° 59′ 23″ N.
	90 0 0		90 0 0
Zen. dist.	57 5 46 N.	Mer. zen. dist.	30 0 37 S.
Declination	16 20 28 S.	Declination	23 24 13 N.
Latitude	40 45 18 N.	*Latitude*	6 36 24 S.

Exs. 10 and 11. Zen. Dist. and Decl. of *different* names, and Decl. greater than Zen. Dist., the Lat. is of the same name as the Decl.

True alt.	86° 53′ 41″ N.	True alt.	70° 31′ 19″ S.
	90 0 0		90 0 0
Mer. zen. dist.	3 6 19 S.	Mer. zen. dist.	19 28 41 N.
Declination	23 21 33 N.	Declination	23 2 54 S.
Latitude	20 15 14 N.	*Latitude*	3 34 13 S.

Ex. 12. Decl. 0. The Zen. Dist. is Lat., N. or S. according as the Zen. Dist. is N. or S.

True alt.	51° 18′ 12″ N. (or S.)
	90 0 0
Mer. zen. dist.	38 41 48 S. (or N.)
Declination	0 0 0
Latitude	38 41 48 S. (or N.)

Ex. 13. Zen. Dist. 0. The Decl. N. or S.

True alt.	90° 0′ 0″
	90 0 0
Mer. zen. dist.	0 0 0
Declination	10 2 53 N. (or S.)
Latitude	10 2 53 N. (or S.)

EXAMPLES FOR PRACTICE.

In each of the following examples the latitude is required:—

No.	Civil date.	Longitude.	Obs. alt. sun's L.L.	Index corr.	Eye.
1.	1887, Jan. 10th,	49° 51′ W.	68° 39′ 40″ N.	+ 5′ 10″	13 ft.
2.	„ Feb. 1st,	39 51 E.	72 43 50 S.	+ 1 42	13
3.	„ April 28th,	165 23 W.	U.L. 82 51 10 N.	+ 4 10	18
4.	„ May 2nd,	32 3 E.	U.L. 46 18 0 S.	0	20
5.	„ June 11th,	62 57 E.	L.L. 42 24 45 N.	+ 2 15	21
6.	„ Sept. 23rd,	166 30 E.	41 36 10 S.	− 4 41	17
7.	„ Oct. 23rd,	90 12 W.	54 40 40 S.	− 0 49	18
8.	„ Nov. 15th,	80 11 E.	67 43 0 S.	+ 1 38	15
9.	„ March 20th,	178 30 W.	61 49 30 S.	− 3 17	15
10.	„ April 7th,	139 45 W.	89 55 50 S.	+ 5 10	12
11.	„ Sept. 23rd,	123 45 E.	83 40 30 S.	0	18
12.	„ Nov. 3rd,	106 0 E.	70 29 45 N.	+ 1 22	19
13.	„ Sept. 23rd,	173 58 E.	71 19 20 S.	+ 3 40	18
14.	„ Feb. 12th,	8 12 W.	29 55 20 S.	− 1 10	19
15.	„ March 21st,	77 45 E.	76 58 15 N.	− 2 20	21
16.	1888, Jan. 1st,	125 32 E.	U.L. 54 57 20 S.	+ 2 10	22

ON AMPLITUDES.

156. The Correction or Error of Compass is found by comparing the bearing of the sun or other celestial body, as shown by the compass, with the true bearing, as found by calculation.

The result as deduced above is generally called the variation, but the effects of the iron in the ship modify the bearing by compass. Every error determined on board ship is compounded of variation proper and deviation, and is the entire correction necessary to be applied to every bearing taken, and course steered, but will vary with the position of the ship's head and heel of the ship. If the iron of the vessel exercise no influence on the compass, the result obtained is only variation, and ought to agree with that registered on the chart.

157. The True Amplitude is the bearing of a celestial body at rising or setting (*i.e.*, when its centre is on the *rational* horizon), from the *true* East or West point, found by calculation, from the latitude of the place and declination of the body, or taken by inspection from a table, of which these quantities are the arguments (Table XLII, Norie, or LIX, Raper).

158. The Observed Amplitude is the bearing of a celestial body at rising or setting from the compass East or West points, found by direct observation with an instrument fitted with a magnetic needle, as the Azimuth Compass.

The magnetic amplitude is distinguished as *observed* or *apparent*, and *corrected*. The *observed* or apparent magnetic amplitude of a celestial body is its bearing from the compass East or West point, when it appears in the sea-horizon of an observer standing on the deck of a ship. The *corrected* magnetic amplitude is the bearing of the body from the compass East or West point, when on the rational horizon, as it would appear to a spectator at the centre of the sphere through an uniform medium. The diurnal circles of the celestial bodies being, except at the equator, inclined to the horizon, and more and more the higher the latitude, any cause which affects the time of rising will affect the apparent amplitude, and in a greater degree as the latitude increases. The following are the causes:—1. The elevation of the observer depresses the sea horizon, while it does not affect the place of the celestial body—hence by reason of the *dip* the body appears to rise before it is truly on the sensible horizon. 2. The great *refraction* at the horizon causes the body to appear to rise considerably before it comes to the sensible horizon. 3. When a body is in the sensible horizon, to an eye at the centre of the sphere it has already passed the rational horizon. This being the effect of *parallax*, is only of importance in the case of the moon. These corrections will be found in Table 59 A, Raper.

RULE LXV.

1°. *With the ship date and longitude in time, find the Greenwich date* (see Rule LVIII, page 179).

The time of sunrise and sunset is generally given in apparent time.

2°. *Take out of* Nautical Almanac, page I, *the sun's declination and correct it for this date* (see Rule LIX, page 183).

3°. *Take from the Table the log. sine of declination, and log. secant of latitude (rejecting* 10 *from the index); the sum of these is log. sine of true amplitude, which take out of Tables.* (Table XXV, Norie, or LXVIII, Raper).

4°. **To name the True Amplitude.**—*If the body is rising, or* A.M., *mark true amplitude* East; *if it is setting, or* P.M., *mark it* West; *mark it also* North *when declination is* North, *or* South *when declination is* South.

The time of sun rising is always A.M., and of sun setting P.M.

(a) *When the declination is* 0, *the true amplitude is* 0; *that is, it is* East *if the object is rising,* West *if it is setting.*

(b) *When the latitude is* 0, *the true amplitude is of the same amount as the declination.*

5°. **Correction or Error of the Compass for the Position of Ship's Head.**—*Under the true amplitude write the observed amplitude; then*—

(a) *If both amplitudes are* North *or both* South, *take their* difference.

(b) *When* one *is* North *and the* other South, *take their* sum.

(c) *If* one *is reckoned from* East *and the* other *from* West, *take the* True Amplitude *from* 180°, *and* change *the* name *from* East *to* West, *or from* West *to* East; *the name as to* North *or* South remains unaltered; *then take their* difference.

The sum *or* difference *(as the case may be) is the* entire correction, or error of the compass.

Note.—The observed amplitude must be reckoned from East or West towards the North or South, and then expressed in degrees and minutes before it is placed underneath the true. Thus, the observed amplitude S.E. by E. ½ E. is E. 2½ points S., or E. 28° 7′ 30″ S. Observed amplitude East or West = 0° 0′; while if observed amplitude is North or South, it will be expressed as E. (or W.) 90° N. (or S.), as the case may be. Again, should the bearing by compass be from N. towards W., or from S. towards W., when true amplitude is E. and N., or E. and S., add 90° to the number of degrees W. of N. or S.; thus, S. by W. would be E. 101° 15′ S., and N. ¾ W. will be E. 98° 26′ N. Also, should the bearing by compass be from N. towards E., or from S. towards E., when true amplitude is W. and N., or W. and S., add 90° to the number of degrees East of N. or S.; thus, S.S.E. will be W. 112° 30′ S., and N. ¼ E. will be W. 92° 45′ N.

6°. **To name the Error of Compass.**—*The correction is named* East *when the true amplitude is to the* right *of observed amplitude;* West *when* true *is to the* left *of* magnetic: the observer being supposed looking from the centre of the compass in the direction of the observed amplitude.

Note.—The learner will find it very useful to draw a figure, thus:—

Make a rough sketch of the compass by drawing two lines crossing at right-angles, the ends of which will represent the four cardinal points, which mark N., S., E., W., (see Fig., Ex. 1); then to name the error of the compass proceed as follows:—Consider the cardinal point from which the amplitude is reckoned as the origin, and draw two straight lines from the centre to represent the true and magnetic amplitudes, and mark their extremities T and M respectively—taking care to place the line T further from the origin if the true be greater than the observed (or magnetic) amplitude, but nearer the origin if the true is less. The arc between M and T is the error which will be East when T is to the right of M, but West if to the left. It is easily seen whether the error of the compass is the sum or difference of T and M.

7°. **To find the Deviation.**—*Under the error of the compass place the variation: then*—

(a) *If they are of* like names, i.e., *are both* East *or both* West, *take their difference.*

(b) *But if they have* unlike names, i.e., *if one is* East *and the other is* West, *take the* sum.

The sum *or* difference *(as the case may be) is the* deviation.

(c) *If the* variation *is* 0, *the* error *of the compass is also the* deviation.

(d) *If the* error *of the compass is* 0, *the* deviation *is of the* same amount *as the* variation.

8°. **To name the Deviation.**—*The* **deviation** *is of the* **same name** *as the* **error,** UNLESS *the* **error** has been subtracted from the **variation,** *in which case the* **deviation** *is of a* **contrary name** *to the* **error,** i.e., *the* **deviation** *is* E. *when the* **error** *is* W., *but* W. *when* **error** *is* E.

Also, when the **error** *is* 0, *the* **deviation** *is of* **opposite name** *to* **variation;** *when* **variation** *is* 0, *the* **deviation** *is of* **same name** *as* **error:** thus—

Error 14° 10′ W.	Error 14° 10′ W.	Error 14° 10′ W.	Error 0° 0′ W.	Error 14° 10′ W.
Var. 2 25 E.	Var. 2 25 W.	Var. 22 25 W.	Var. 22 25 W.	Var. 0 0
Dev. 16 35 W.	Dev. 11 45 W.	Dev. 8 15 E.	Dev. 22 25 E.	Dev. 14 10 W.

9°. Otherwise the observer must suppose himself in the *centre* of the compass, looking in the direction of the variation,—then *the deviation is* East *when the* error of compass *is to the* right *of the* variation; West *when the* error of compass *is to the* left *of the* variation—*both the error of the compass and the variation being reckoned from the* North *point of the compass.*

NOTE.—It will be convenient for beginners to draw a figure for the deviation, thus:—(See Fig. 50, Ex. 1).

Make a rough sketch of the compass; the upper part of the vertical line being taken to represent the origin, which mark N., and mark the extremities of the horizontal line W. and E. respectively. Then from the centre of the compass draw two lines to represent the error of compass and the variation, calling them E and V respectively. The line E must be drawn to the right of N. if the error of compass is E., but to the left of N. if the error be W.; similarly, the line V must be to the right of N. when the variation is E., but to the left of N. if the variation is W. Take care to draw E further from N. than V if the error of compass is greater than the variation, but nearer to N. if the error is the less. The deviation is the distance from V to E, and is East when E is to the right of V, but West when E is to the left of V. It is easily seen whether the deviation is the sum or difference of E and V.

NOTE.—In the following examples the seconds of declination are rejected. When the seconds are 30, or above, 1 is added to the minutes; but when they are below 30 nothing is added to the minutes.

EXAMPLES.

Ex. 1. 1887, January 6th, at 4ʰ 44ᵐ 27ˢ A.M., apparent time at ship, lat. 37° 59′ S., long. 36° 24′ W., the sun's bearing by compass was S.E. by E. ½ E.: required the true amplitude and error of compass; and supposing the variation to be 3° 40′ E., required the deviation for the position of the ship's head at the time of obervation.

Ship date (A.T.) Jan.	5ᵈ 16ʰ 44ᵐ 27ˢ
Long. in time	+ 2 25 36
Green. date (A.T.) Jan.	5 19 10 3
Time from noon, Jan. 6th,	4 50 = 4ʰ·83

☉'s Decl., page I, N.A.
Jan. 6th, noon, 22° 30′ 8″ S., *decr.*

H. diff., noon, Jan. 6th	− 18″·06
Time from noon, 4ʰ 50ᵐ	× 4·83
	5418
	14448
	7224
	6,0)8,7·2298
Correction	+ 1 27·3
Decl., Jan. 6th, noon	22 30 8 S. (—)
Red. decl.	22 31 35 S.

Or thus, Var. in 1ʰ.

	Jan. 6th, noon	18″·06
		5
10ᵐ	⅙ʰ	90·30
		− 3·01
	6,0	8,7·29
		1 27·3

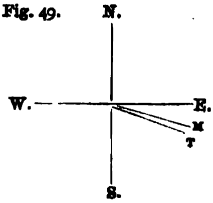
The declination is here taken for the nearest noon, viz., the 6th, and since the Green. time wants only 4ʰ 50ᵐ of being noon of 6th (24ʰ 0ᵐ — 19ʰ 10ᵐ = 4ʰ 50ᵐ), multiply the hourly diff. by this quantity, and apply the resulting correction the *opposite* way, since the declination is *decreasing* the declination at 4ʰ 50ᵐ before noon will be more than it is at noon, hence we add the correction. Or, multiply by 5ʰ, then since 5ʰ is 10ᵐ in excess of 4ʰ 50ᵐ, deducting 1-5th of H.D. from the product above, the result is the *correction* of declination.

Decl	22° 32′	sine	9·583449
Lat.	37 59	secant	0·103369
		sine	9·686818

(A.M. and S. decl.)	True amp.	E. 29° 5½′ S.	Amplitudes *same* name, take their *difference.*
(S.E. by E. ½ E.) (= E. 2½ pts. S.)	Obs. amp.	E. 28 7½ S.	

Error of compass 0 58 E., because *true* amplitude is to the *right* of *magnetic* amplitude.

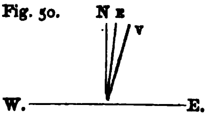
Fig. 49.



To find the Deviation.

Error of compass	0° 58′ E.	Error and var. *same* name, take the *difference.*
Variation by chart	3 40 E.	
Deviation	2 42 W., because the *error* of compass is to the *left* of the variation.	

Fig. 50.



Otherwise:—By 8° of Rule, the error being *subtracted from* the variation, the deviation is of the *opposite* name to the error, *i.e.*, the error being E., the deviation is named W.

Make a rough sketch of the compass as in Fig. 49 in the above example. In this example the magnetic amplitude is reckoned from E. towards S. (S.E. by E. ½ E. = E. 2½ pts. S. = E. 28° 7½′ S.) To represent this, draw a line from the centre of the compass to a point M, somewhere between E. and S. Again, the true amplitude is reckoned from E. towards S. To represent this, draw a line from the centre of the compass to point T, further from E than M is from E, because the true amplitude is greater than the magnetic amplitude. Then it is evident that the line T, or the true amplitude, is to the *right* of the line M, or the magnetic amplitude. Hence, by Rule, 6°, the error of the compass is East.

Again, to name the deviation:—Draw a figure (see Fig. 50 above) and mark the end of the vertical line N, to represent the true meridian (or true N. point), and the extremities of the horizontal line W and E respectively, to represent West and East. Next, from the centre of the compass draw a line E (see Fig. 50) to the *right* of North, to represent the Error of the Compass, which is E.; and since the variation is also East, draw another line V to the *right* of North, but further from N than E is, because the variation is *greater* than the error. (See Fig. 50.) It is evident that the deviation is the angle included between E and V, and is West because E, the error, is to the *left* of V, the variation (Rule, 7° and 9°). It is evident too that in this instance the deviation is the difference of E and V.

Ex. 2. 1887, February 16th, at $4^h\ 58^m$ P.M., apparent time at ship, latitude 51° 9′ N., longitude 15° W., sun's observed amplitude W. ½ N.: required the true amplitude and error of the compass; and supposing the variation to be 30° 30′ W.: required the deviation for the position of the ship's head at the time of observation.

Ship date (A.T.) Feb. $16^d\ 4^h58^m$
Long. 15° 0′ W. + 1 0
Green. date (A.T.) Feb. 16 5 58
or, $5^h{\cdot}97$

Var. $1^h = 52''{\cdot}02$
6^h
$2^m \mid \frac{1}{30}{}^h$ | 312·12 = Corr. for 6^h
— 1·73 = „ 2^m
6,0 | 31,0·39 = „ 5^h58^m
Corr. 5 10

Sun's decl., page I, N.A., Feb. 16th, *noon* 12° 19′ 49″ S., *decr.*

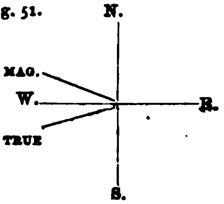
H. diff., noon, Feb. 16th — 52″·02
5·97
36414
46818
26010
6,0)31,0·5594
5 10·56

Correction — 5 11
Decl., noon, Feb. 16th, 12 19 49 S. *decr.*
Red. decl. 12 14 38 S.

Declination 12° 15′ sine 9·326700
Latitude 51 9 secant 0·202536
sine 9·529236

(P.M. and S. decl.) True amp. W. 19° 46′ S.
(W. ½ pt. N.) Mag. amp. W. 2 49 N.
Amplitudes *different* names, take the *sum.*
Error of compass 22 35 W., the *true* amplitude being to the *left* of *magnetic.*

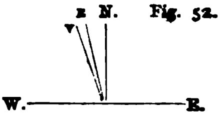
Fig. 51.



To find the Deviation.

Error of compass 22° 35′ W.
Variation 30 30 W.
Error and var. *same* name, take the *difference.*
Deviation 7 55 E., because the *error* is to the *right* of the variation.

Fig. 52.



Otherwise:—Error being *subtracted* from variation, the deviation is of *contrary* name to the error, *i.e.*, deviation is E.

Ex. 3. 1887, April 13th, at $5^h\ 47^m\ 20^s$ A.M., apparent time at ship, latitude 20° 2′ N., longitude 107° 56′ E., sun's bearing by compass E. ½ N., variation 1° 40′ E.

Ship date (A.T.) April $12^d\ 17^h47^m20^s$
Long. 107° 56′ E. — 7 11 44
Green. date (A.T.) April 12^d 10 35 36
or, $10^h{\cdot}6$

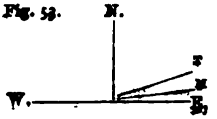
H. diff., April 12th, noon + 54″·72
Time *past* noon $10^h\ 36^m$ = 10·6
32832
5472
6,0)58,0·032
9 40

Declination 8° 50′ sine 9·186280
Latitude 20 2 secant 0·027106
sine 9·213386

Correction + 9′ 40″
Decl., 12th, noon 8° 40 7 N. *incr*
Red. decl. 8 49 47 (N.

(A.M. and N. decl.) True amp. E. 9° 24′ N.
(E. ½ pt. N.) Mag. amp. E. 2 49 N.
same name take *difference.*
Error of compass 6 35 W., the true amplitude being to the *left* of *magnetic.*

Fig. 53.



To find the Deviation.

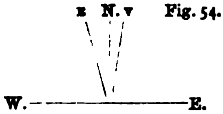


Fig. 54.

Error of compass 6° 35′ W. } Different names,
Variation 1 40 E. } take the *sum*.

Deviation 8 15 W., because the *error* is to the *left* of the *variation;* or the deviation is of the *same* name as the error of compass.

Ex. 4. 1887, Sept. 23rd, at $6^h\ 0^m$ A.M., apparent time at ship, latitude 24° 40′ S., longitude 45° 31′ W., sun's magnetic amplitude W. 2° 50′ N., variation 7° 40′ E.

Ship date, Sept. $22^d\ 18^h\ 0^m\ 0^s$
Long. 45° 31′ W., in time + 3 2 4
Green. date, Sept. 22 21 2 4
Time *before* Sept. 23rd 2 58

H. diff., noon, Sept. 23rd — 58″·49
$2{\cdot}96^h$
6,0)17,3·1304
Correction — 2 53
Decl., 23rd, noon 0 2 53 S., *incr.*
Red. decl. 0 0 0

The decl. being 0° the true amplitude is 0°, or W. 0° 0′, whence the error of compass is 2° 50′ W., because the *true* amplitude is to *left* of magnetic.

To find the Deviation.

Error of compass 2° 50′ W. } Error and variation of *different*
Variation 7 40 E. } names, take their *sum*.

Deviation 10 30 W., because the error of compass is to the *left* of variation.

Ex. 5. 1887, December 9th, at $8^h\ 27^m$ A.M., apparent time at ship, latitude 54° 35′ N., longitude 53° 15′ W., sun's magnetic amplitude S.E. ½ E., variation 36° 20′ W., ship's head S.E. ½ E.

Ship date (A.T.), Dec. $8^d\ 20^h\ 27^m\ 0^s$
Long. in time + 3 33 0
Green. date, Dec. 8 24 0 0
or, Dec. 9 0 0 0

Decl. at noon, Dec. 9th, 22° 49′ 46″ S.

The Green. date being noon, Dec. 9th, one of the instants for which the decl. is put down in the *Almanac*, nothing more is necessary than to transcribe the quantity as there put down.

Declination 22° 50′ sine 9·588890
Latitude 54 35 secant 0·236933
sine 9·825823

(A.M. and S. decl.) True amp. E. 42° 2′ S. } *Same* name, take
(E. 3½ pts. S.) Mag. amp. E. 39 22½ S. } their *difference*.

Error of compass 2 39½ E., the true amplitude being to
Variation 36 20 W., the *right* of magnetic.

Deviation 38 59½ E., because the error is to the *right* of variation.

Ex. 6. 1887, July 1st, at $8^h\ 36^m$ P.M., apparent time at ship, latitude 56° 4′ N., longitude 64° 50′ W., sun's setting amplitude North, variation 30° 0′ W.

Ship date (A.T.), July $1^d\ 8^h\ 36^m\ 0^s$
Long. in time + 4 19 20
Green. date, July 1 12 55 20
or, $12^h{\cdot}92$

Decl., page I, N.A., July 1st, at noon, 23° 7′ 36″·6 N., *decr.*; var. $1^h = 9''{\cdot}98$; then $9''{\cdot}98 \times 12^h{\cdot}92 = 128''{\cdot}9416$, or 2′ 8″·9, the correction, which *subtracted* from decl. at noon, 23° 7′ 37″ N., gives Red. decl. 23° 5′ 28″ N.

Declination 23° 5½′ sine 9·593511
Latitude 56 4 secant 0·253188
44 38 sine 9·846699

(P.M. and N. decl.)	True amp.	W. 44° 38′ N.	
	Obs. amp.	W. 90 0 N.	(8 pts. = 90°)
	Error of compass	45 22 W.,	because the amplitude is to the *left* of observed bearing.
	Variation	30 0 W.	
	Deviation	15 22 W.,	because error is *left* of variation

Ex. 7. 1887, June 19th, at $9^h 40^m$ P.M., apparent time at ship, lat. 62° 31′ N., long. 30° 24′ W., sun's setting amplitude N.N.E.; and supposing the variation of the compass is 57° 50′ W., required the deviation for the position of the ship's head at the time the observation was taken.

Ship date (A.T.)	June 19^d	$9^h 40^m 0^s$
Long. (30° 24′ W.) in time	+	2 1 36
Green. date (A.T.) June 19th		11 41 36
		$11^h{\cdot}7$

H. diff., 19th	2″·35
T. from noon	× 11·7
Corr. of decl.	27·495
Decl., June 19th, noon	23°26′ 2″N. *incr.*
Corr.	+ 27
Red. decl.	23 26 29 N.

Declination	23°26½′	sine	9·599681
Latitude	62 31	secant	0·335837
		sine	9·935518

(P.M. and N. decl.)	True amplitude	W. 59°33′ N.	
		180 0	
		E. 120 27 N.	
(E. 6 pts. N.)	Mag. amplitude	E. 67 30 N. = N.N.E.	
	Error of compass	52 57 W.,	because *true* amplitude is to the *left* of mag. amplitude.
	Variation	57 50 W.	
	Deviation	4 53 E.,	because error is to the *right* of *variation.*

Or, the error of compass being *subtracted* from the variation, the deviation is of the *same* name as the error.

Otherwise:—Having found the true amplitude, which is reckoned from W. to N., we may add 90° to the number of degrees the observed bearing is East of North, whence we have the observed amplitude (22° 30′ + 90) = W. 112° 30′ N.

(P.M. and N. decl.)	True amplitude	W. 59°33′ N.	
(W. 11 pts. N.)	Mag. amplitude	W. 112 30 N. = N.N.E.	
	Error of compass	52 57 W.,	because true amplitude is to the *left* of mag. amp.
	Variation	57 50 W.	
	Deviation	4 53 E.	

The true and observed amplitudes must both be reckoned *from the same point* of the compass, E. or W., but in this instance one is reckoned from W. and the other from E.; therefore, by taking either of them from 180°, they would both be reckoned from the same point —the true amplitude, in this example, is taken from 180°, and it is then reckoned from E. instead of W. Next take the difference of the amplitudes, as they are both marked N.; and since the true amplitude is to the *left* of the magnetic—looking from the centre of the compass in the direction of the magnetic—the error of compass is W. The error of compass and variation being of the same name, take their difference for the deviation, which mark E., because the error of the compass is to the right of variation, looking from the centre of the compass in the direction of the variation.

EXAMPLES FOR PRACTICE.

In each of the following examples the Error of Compass and Deviation are required for the position of the ship's head at the time of observation.

No.	Civil Date.	App. Time.	Latitude.	Longitude.	Sun's Obs. Amp.	Variation.
	1887.	h m s	° ′	° ′		° ′
1	Jan. 27th....	6 55 40 A.M.	35 42 N.	12 52 W.	S.E. by S.......	21 50 W.
2	Feb. 17th....	6 48 0 P.M.	34 57 N.	40 8 E.	S.W. by W.....	7 40 E.
3	March 29th..	5 50 0 A.M.	25 50 S.	127 35 W.	E.S.E.	23 40 W.
4	April 5th....	6 15 0 P.M.	20 20 S.	155 30 E.	W. 6° 40′ N. ..	6 40 E.
5	Nov. 7th	5 25 0 A.M.	27 41 S.	70 2 W.	E. ¼ N.........	13 50 E.
6	June 2nd....	8 8 2 P.M.	52 30 N.	27 6 W.	N.N.W. ¼ W...	37 20 W.
7	July 14th....	6 50 58 A.M.	28 59 S.	111 11 W.	N.E. ¼ N.......	11 40 E.
8	Aug. 1st	4 1 0 A.M.	59 10 N.	178 14 W.	N. 1° 30′ W.....	19 40 E.
9	Sept. 8th	5 47 0 A.M.	24 22 N.	57 30 W.	East	0 0
10	Oct. 31st	4 40 50 A.M.	54 14 S.	175 15 E.	S. 81° 20′ E....	28 50 E.
11	Sept. 23rd ..	6 0 0 A.M.	56 41 S.	179 42 E.	E. ¼ S.	11 0 E.
12	Aug. 18th ..	7 21 48 P.M.	59 59 S.	160 45 E.	North	36 50 W.
13	March 20th..	6 0 0 P.M.	55 10 N.	62 46 W.	West	15 0 E.
14	Sept. 23rd ..	6 0 0 A.M.	60 1 S.	45 32 W.	East	21 50 W.
15	June 9th	6 0 0 A.M.	0 0	10 21 W.	E. ½ N.........	20 15 W.
16	Feb. 26th....	7 49 0 A.M.	62 5 N.	12 52 W.	S.S.E.	35 45 W.
17	June 18th ..	1 47 0 A.M.	63 54 N.	174 20 W.	N. by W. ¼ W...	25 0 E.
18	Mar. 6th	6 14 0 P.M.	31 24 S.	2 10 E.	W. 16° 52′ N. ..	17 50 W.
19	April 10th ..	6 45 0 P.M.	53 58 N.	178 33 E.	W. ¾ S.........	16 10 E.
20	Dec. 14th....	4 35 0 A.M.	42 0 S.	74 56 E.	South	19 20 W.

ON FINDING THE TIME OF HIGH WATER.

"BY THE ADMIRALTY TIDE TABLES."

159. These Tide Tables, published annually, give the *time* (A.M. and P.M.) *of high water, and the height for every day in the year*, at the following places, viz.:—Brest, Devonport, Portsmouth, Dover, Sheerness, London, Harwich, Hull, Sunderland, North Shields, Leith, Thurso, Greenock, Liverpool, Pembroke, Weston-super-mare, Holyhead, Kingston, Belfast, Londonderry, Sligo Bay, Galway, Queenstown, and Waterford.

160. To find the times of high water from the Tide Tables if the place is one of the Standard Ports, proceed by

RULE LXVI.

Turn to the month in the Tide Tables and find the given place; then opposite *the* given date *will stand the* morning (A.M.) *and* afternoon (P.M.) *times of high water required.*

NOTE.—When the mark — occurs it shows that there is but one tide during that day; no high water, therefore, takes place in the morning or afternoon in which the mark appears.

Thus, wishing to know the time of high water at North Shields on the 1st of February, 1885—on turning to February under the head of North Shields (see page 13), it is seen at a glance that high water takes place at $4^h\ 20^m$ A.M., and that the height of tide is 14 ft. 2 in. *above the mean low water level of spring tides*, and that the time of high water on the afternoon of same day is $4^h\ 43^m$, while the height of tide above the low water level of spring tides is

14 ft. 2 in. Similarly, desiring to know the particulars of the tide at Brest on the morning of April 10th, 1885 (see page 26), the mark — shows that no tide occurs on the morning of that day; there will be a high water at $11^h\ 41^m$ P.M. on the 9th, and again at $0^h\ 18^m$ P.M. (*i.e.*, 18^m past noon of the 10th April, but none in the interval.

Again, if it be required to know the times of high water on May 1st, 1885, at Weston-super-mare—on turning to May, and under Weston-super-mare (see page 39), and opposite the 1st we find that the times of high water are $8^h\ 0^m$ A.M., and $8^h\ 16^m$ P.M. respectively.

161. If the place at which the time of high water is required be not a Standard Port, it is to be referred (if in the west of Europe) to a **Standard Port,** by adding or subtracting a certain constant to the time of that Standard Port, as directed in the Tables.

In pages 103 to 108 of the Admiralty Tables, 1885, will be found upwards of two hundred ports on the coasts of the United Kingdom, and in Europe, for which Standard Ports of Reference are given, and the time which is to be added to or subtracted from the time of high water at such Standard Port.

162. To find the times of high water by the Tidal Constants.

RULE LXVII.

1°. *Seek in the "Tide Tables," pages* 104-108, *in the* left-hand column *for the* given place, *or port you wish the time of high water for, and in the column headed* "Standard Port for Reference," *will be found the* Standard Port *for the given place; also, from the middle column headed* "Time," *and* opposite *the* given place, *take out the* "Constant," *being careful to note whether it is* additive (marked +), *or* subtractive (marked —).

2°. *Take out of "Admiralty Tide Tables," pages* 1-97, *the* morning (A.M.) *and* afternoon (P.M.) *times of high water at the* "Standard Port for Reference," *being careful to annex the letters* A.M. *or* P.M. *to the tides so taken out.*

(a) *If a blank* (——) *occurs in either* morning (A.M.) *or* afternoon (P.M.) *column, use the* preceding time of high water **instead** *when the Constant is marked* additive (+), *but use the* time of high water following *the blank* (——) *when the difference is marked* subtractive (—).

3°. *To the times of high water at the* Standard Port *just taken out,* apply *the* Constant (No. 2°), adding *or* subtracting *said Constant according as it is marked* + *or* —; the result *in each case,* if less *than* 12^h, *is respectively the* morning (A.M.) *and* afternoon (P.M.) *times of high water required.* (See Exs. 1 and 2).

(a) *When the* sum *of the* Constant *and the* morning (A.M.) *time of high water at the* Standard Port *exceeds* 12^h, *deduct* 12^h, *the remainder is the* afternoon (P.M.) *time of high water at the given place.* To obtain the morning (A.M.) time of high water at the given place, *if any,* add *the* Constant *to the* **preceding afternoon** (P.M.) *time of high water at the* Standard Port, *and if the* sum exceeds 12^h, deduct 12^h, *the remainder is the* morning (A.M.) *tide sought* (Ex. 3), but *if the* **sum be less than** 12^h, *it is the* afternoon (P.M.) *tide of the* day before, *and* **there is no morning** (A.M.) **tide that day at the given place.** (Ex. 4).

(b) *When the Constant* added *to the* morning (A.M.) *time of high water at the* Standard Port *is* **less than** 12^h (i.e., *gives* morning (A.M.) *tide at given place*), *but when* added *to the* afternoon (P.M.) *tide at the* Standard Port *is* **greater** *than* 12^h, *there is* **only a morning** (A.M.) **tide** *at the given place on that day*. (Ex. 5).

NOTE.—When the sum of the Constant and the tide taken from the Tables is less than 12^h, it remains a tide of the *same name as that used*, but when the sum exceeds 12^h, the time *over* 12^h will be a tide of *the name following* that taken out; consequently, in such a case take from the Tables the tide immediately preceding the one you require.

(c) *When the Constant is* subtractive, *and* **exceeds** *the* morning (A.M.) time of high water *at the* Standard Port, reject *this last* and use *the following* afternoon (P.M.) tide *at the* Standard Port (Ex. 10). *If the* subtractive Constant **exceeds** the afternoon (P.M.) tide *at* Standard Port, 12^h *must be* added *to this last before* subtraction *is made*, the remainder *will be the* morning (A.M.) tide *at the given place*. *For the* afternoon (P.M.) tide *use the following tide at* Standard Port, *that is, the* morning (A.M.) time of high water next day, *borrowing* 12^h *if Constant* exceeds *it, the remainder is* afternoon (P.M.) tide *at the given place* (Ex. 10).

(d) *If* Constant *being* subtractive, exceeds *the* Standard Port morning (A.M.) high water, *but is* less *than the* Standard afternoon (P.M.) tide, *there is only an* afternoon (P.M.) tide *at the given place on that day* (Ex. 12).

(e) *If when the* Constant *is* subtractive, *the* Standard Port afternoon (P.M.) tide *has to be* increased 12^h, *but* Constant *is* less *than the* Standard morning (A.M.) tide following; *there is* only *a* morning (A.M.) tide *at the given place that day*.

Short Rule for Blank.—*First apply the* Constant *to the* tide given; *then, if* Constant *is* + *borrow last night's tide, but if* — *borrow next morning's tide, being careful to use the given tide first. In either of the above cases should the tide prove useless, then write down* no A.M. *or* no P.M., *according to the result of the given tide.*

EXAMPLES.

Ex. 1. 1885, January 16th: find the times of high water at Scarborough.

Turning to Admiralty Tide Tables for 1885, at page 106, in the left-hand column, and under the head of "Ports of Great Britain," we find Scarborough, and in the right-hand column, immediately abreast, we find that the Standard Port for Reference in this instance is Sunderland, and in the column under Time we have the Constant $+ 0^h 49^m$; that is, we have to *add* $0^h 49^m$ to the time of high water at Sunderland on any day in order to obtain the corresponding time of high water at Scarborough. The work will stand as follows:—

Port for Reference—Sunderland, Jan. 16th	$3^h 25^m$ A.M.		Jan. 16th	$3^h 42^m$ P.M.
Constant for Scarborough	+ 0 49			+ 0 49
Time of H.W. Scarborough, Jan. 16th	4 14 A.M.		Jan. 16th	4 31 P.M.

Ex. 2. 1885, January 7th: find the times of high water A.M. and P.M. at the Needles Point.

Turning to the "Admiralty Tide Table" for 1885, at page 107, in the left-hand column, we find Needles Point, and in the right-hand column, immediately abreast, we find that the Standard Port for Reference, which in this instance is Portsmouth, and in the column under Time we have the Constant — $1^h 55^m$; that is, we have to *subtract* $1^h 55^m$ from the time of high water at Portsmouth on any day in order to obtain the corresponding time of high water at Needles Point. The work will stand as follows:—

Port for Reference—Portsmouth, Jan. 7th	$3^h 42^m$ A.M.		Jan. 7th	$4^h 4^m$ P.M.
Constant for Needles	— 1 55			— 1 55
Times H.W. Needles, Jan. 7th	1 47 A.M.		Jan. 7th	2 9 P.M.

It may be here remarked, that on adding a ***Constant*** to the time at the Standard Port for Reference, a morning tide frequently becomes an afternoon tide, and an afternoon tide may become a morning tide ***for the next day***, in which case the afternoon tide of the previous day must be employed to find the morning tide at the given port. (See 3° (a) of Rule).

Ex. 3. 1885, May 9th: find times of high water, A.M. and P.M., at Cherbourg.

The Standard Port for Reference for Cherbourg (see page 108, Admiralty Tide Tables) is Brest, and the Constant is + $4^h\ 2^m$, that is, for the times of high water at Cherbourg we must always add $4^h\ 2^m$ to the times of high water at Brest.

In this instance, high water at Brest, May 9th, occurs at $11^h\ 21^m$ A.M. (*i.e.*, 39^m before noon); consequently, $4^h\ 2^m$ (the Cherbourg Constant) added to that time must evidently give a P.M. tide at Cherbourg; the A.M. high water at Cherbourg must, therefore, be sought from the previous (P.M.) tide at Brest. When the *additive* constant is applied to the preceding afternoon (P.M.) tide ($10^h\ 45^m$), the *sum* exceeds 12^h, consequently the tide flows past midnight—the excess of 12^h being evidently the morning (A.M.) tide at Cherbourg. The work stands as follows:—

Port for Reference—Brest, H.W., May 9th	11^h21^m A.M.	May 8th	10^h45^m P.M.
Constant for Cherbourg	+ 4 2		+ 4 2
	15 23		14 47
	− 12		− 12
Times H.W. Cherbourg, May 9th	3 23 P.M.	May 9th	2 47 A.M.

If the morning tide, by **adding a Constant,** is more than 12^h, and thus becomes an afternoon tide, but the afternoon tide of the day before *remains less than* 12^h when the Constant is added, then there is **no morning high water** at the required port (Rule, 3°, (a), thus:—

Ex. 4. 1885, August 10th: find A.M. and P.M. tides at Flushing.

The Standard Port for Reference in this case is Dover, and the Constant + $1^h\ 42^m$. (See page 108).

In this case it is high water at Dover, Aug. 10th, at $10^h\ 34^m$ A.M. (*i.e.*, $1^h\ 26^m$ before noon), and the Constant $1^h\ 42^m$ added to that will evidently give a P.M. tide at Flushing. The preceding time of high water at Dover, *i.e.*, the time of high water in the afternoon (P.M.) of the previous day must be employed to obtain the morning (or A.M.) tide at Flushing—if any. In this example it will be seen that when the *additive* constant is applied to the preceding afternoon tide at Dover, the sum is less than 12^h, consequently, the tide does not flow *past midnight*—the result being P.M. tide of Aug. 9th. There is, therefore, no A.M. tide on the 10th of August at Flushing.

Time H.W. Dover, Aug. 10th	10^h34^m A.M.	Aug. 9th	$10^h\ 6^m$ A.M.
Constant	+ 1 42		+ 1 42
	12 16	Aug. 9th	11 48 P.M.
	− 12		
Time H.W. Flushing, Aug 10th	0 16 P.M.	(No A.M. tide.)	

So, also, if, when the Constant is added to the morning (A.M.) time of high water, the time is less than 12^h, but when added to the afternoon time is greater than 12^h, there is **only a morning** time of high water at the given port. (Rule, 3°, (b).

Ex. 5. 1885, April 22nd: find the time of high water, A.M. and P.M. at Lyme Regis.

Turning to page 107 of the Admiralty Tide Tables for 1885, it will be seen that the Standard Port for Reference in this instance is Devonport, and the Constant is + $0^h\ 38^m$, *i.e.*, in order to obtain the time of high water on any given day we must *add* $0^h\ 38^m$ to the times of high water at Devonport on that day.

Port for Reference—Devonport, April 22nd	10^h56^m A.M.	April 22nd	11^h30^m P.M.
Constant	+ 0 38	Constant	+ 0 38
H.W. Lyme Regis, April 22nd	11 34 A.M.	April 22nd	12 8 P.M.
		or, April 23rd	0 8 A.M.

∴ H.W. Lyme Regis, April 22nd, $11^h\ 34^m$ A.M.; no P.M.

It also frequently occurs that *when there is but one high water at the Standard Port*—a blank (—) occuring in one of the columns—there may *be two at the given port.*

(a) When there is only a **morning time** of high water at the Standard Port, *i.e.*, a blank occurs in P.M. column, and the *Constant is additive*, the morning tide may become an afternoon tide, and the afternoon tide of the day before may become the morning tide required, thus:—

Ex. 6. 1885, December 1st: find times of high water, A.M. and P.M., at Morlaix.

Referring to page 107, Admiralty Tide Tables for 1885, it will be seen that the Standard Port for Reference in this case is Brest, and the Constant is + $1^h\ 6^m$. There is only one high water at the Standard Port, which occurs at $11^h\ 35^m$ A.M., *i.e*, $0^h\ 25^m$ *before noon.* The constant + $1^h\ 6^m$ being *added* to this morning time evidently gives the afternoon (P.M) tide (see Rule 3° (a); and the morning (A.M.) tide is sought by applying the constant to the *previous* afternoon (P.M.) tide, which occurs on Nov. 30th, (the last day of the previous month) at $10^h\ 58^m$ P.M., *i.e.*, $1^h\ 2^m$ before midnight; the result is Nov. 30th, $12^h\ 4^m$ P.M., which is equivalent to December 1st, $0^h\ 4^m$ A.M.

Brest, H.W., December 1st		$11^h\ 35^m$ A.M.	Brest, November 30th		$10^h 58^m$ P.M.
Constant for Morlaix	+	1 6	Constant	+	1 6
		12 41			12 4 P.M.
	—	12		—	12
Morlaix, H.W., Dec. 1st		0 41 P.M.	H.W., December 1st		0 4 A.M.

This example shows the method of proceeding when the first tide has to be taken from the first day of one month and the second tide from the last day of the preceding month.

(b) When there is only an **afternoon** (P.M.) time of high water at the Standard Port, *i.e.*, when a blank (—) occurs in the morning (A.M.) column at Standard Port, and the *Constant is additive*, the *previous* afternoon (P.M.) time of high water at the Standard Port may become the morning (A.M.) time of high water at the given port, while the afternoon (P.M.) time of high water at the Standard Port may give the afternoon (P.M.) time of high water required, thus:—

Ex. 7. 1885, August 2nd: find A.M. and P.M. times of high water at Stromness.

The Standard Port for Reference is Thurso, and the constant is + $0^h\ 32^m$ (page 106, Admiralty Tide Tables, 1885). A blank occurring in the morning (A.M.) column of the Standard Port for Reference, shows that there is *no morning* tide at that place, only an *afternoon* time of high water. The Constant being *additive*, we must take out the high water for the *previous* afternoon (P.M.), which is $11^h\ 50^m$ P.M. on the 1st, *i.e.*, $0^h\ 10^m$ *before* midnight on the 1st; the Stromness Constant, + $0^h\ 32^m$, *added*, evidently gives the *next morning* (A.M) tide at Stromness, since $12^h\ 22^m$ past noon August 1st is evidently $0^h\ 22^m$ A M. on August 2nd. The afternoon (P.M.) time of high water at Stromness is found by *adding* the Stromness Constant to the afternoon (P M.) time of high water at Thurso. The work stands thus:—

Standard Port for Reference—Thurso; Constant + $0^h\ 32^m$.

Thurso, H.W., August 1st		$11^h 50^m$ P.M.	H.W., August 2nd		$0^h 12^m$ P.M.
Constant	+	0 32	Constant	+	0 32
August 1st		12 22 P.M.	H.W., August 2nd		0 44 P.M.
		12			
Stromness, August 2nd		0 22 A.M.			

It sometimes happens that when there *is but one high water* at the Standard Port, there *may be but one* at the given port.

(a) When a blank (——) occurs in the **morning** column for the given day at the Standard Port, *i.e.*, when there is *no morning* tide at that place, and the Constant being *additive*, the *previous* afternoon (P.M.) time of high water at the Standard Port may give the afternoon (P.M.) tide at the given port for-the previous day, and the afternoon (P.M.) time of high water at the Standard Port for the given day gives the afternoon (P.M.) time of high water for the same day at the given port.

Ex. 8. 1885, May 30th: find times of high water, A.M. and P.M., at Boulogne.

The Standard Port for Reference for Boulogne is Dover, and the Constant is + $0^h\ 13^m$ (see Admiralty Tide Tables, 1885, page 108). A blank occurring in the morning (A.M.) column of Port for Reference (Dover), and the Constant being *additive* (+), the preceding time of high water, *i.e.*, that for the afternoon (P.M.) of the *previous* day is used to determine the morning tide at Boulogne—if any. In this example it will be seen that on applying the Constant to the previous P.M. tide at Dover, the sum ($11^h\ 54^m$) is *less* than 12^h, consequently, it remains a P.M. tide of the preceding day—the 29th.

There is *no* A.M. tide. The Constant added to the afternoon tide of given day at the Standard Port gives the required afternoon tide at Boulogne.

Time H.W., Dover, May 29th	11^h41^m P.M.	Dover May 30th (noon)	$0^h\ 0^m$
Constant for Boulogne	+ 0 13	Constant	+ 0 13
Time H.W., Boulogne, May 29th	11 54 P.M.	Boulogne, May 30th	0 13 P.M.

No A.M. tide; $0^h\ 13^m$ P.M.

(b) When a blank (—) occurs in the **afternoon** (P.M.) column for the given day, *i.e.*, when there is *no afternoon* tide at the Standard Port and the Constant is *additive* (+) the *previous* afternoon (P.M.) time of high water at the Standard Port may give the afternoon (P.M.) tide at the given port for the previous day, and the morning (A.M.) time of high water at the Standard Port for the given day gives the afternoon (P.M.) time of high water for the same day at the given port.

Ex. 9. 1885, July 22nd: find A.M. and P.M. times of high water at Hartlepool.

The Standard Port for Reference for Hartlepool is Sunderland, and the Constant + $0^h\ 6^m$. There is *no afternoon* tide on July 22nd at Standard Port. The morning time of high water at Sunderland is $11^h\ 54^m$ A.M., or $0^h\ 6^m$ *before* noon, and the Constant $0^h\ 6^m$ *added* gives NOON as the time of high water at the given port.

Time of H.W., Sunderland, July 22nd	11^h54^m A.M.
Constant for Hartlepool	+ 0 6
	12 0 A.M.
	or Noon.

When the Constant is **subtractive,** the morning tide at the Standard Port frequently becomes an afternoon tide of the **day before,** and the afternoon tide of the given day becomes a morning tide, in which case the morning tide of the succeeding day must be employed to find the afternoon tide at the given port, as in the example following:—

Ex. 10. 1885, May 6th: find A.M. and P.M. tides at Portland Breakwater.

In this case the Standard Port for Reference is Portsmouth, and the first tide at Portsmouth occurs at $4^h\ 1^m$ A.M. (*i.e.*, $4^h\ 1^m$ after midnight), consequently, since Portland Constant shows that high water occurs there $4^h\ 40^m$ earlier than at Portsmouth, and since that quantity subtracted from May 6th, $3^h\ 37^m$ A.M., would give a P.M. tide on the 5th at Portland; we, therefore, use the Portsmouth tide of the 6th P.M., and of the 7th A.M., thus:— (See Rule, (c)).

Time H.W., Portsmouth, May 6th	$4^h\ 1^m$ P.M.	May 7th	4^h27^m A.M.
	+ 12		+ 12
	16 1		16 27
Constant for Portland	— 4 40		— 4 40
Times H.W., Portland Breakwater, May 6th	11 21 A.M.	May 6th	11 47 P.M.

When at the Standard Port there is only **an afternoon** high water, and the Constant is *subtractive*, and *greater* than the given time, the afternoon tide for the *given day* will give the morning tide required, and the morning time of high water for the succeeding day must be employed to determine the afternoon time (Rule, (e), thus :—

Ex. 11. 1885, July 7th: find A.M. and P.M. tides at Falmouth.

The Standard Port for Reference is Devonport, and the Constant is — $0^h 46^m$ (Admiralty Tide Tables, page 107). A blank (——) occurs in the morning column of the 7th, we therefore use the next tide (as the Constant is *subtractive*), viz., the P.M. tide, 12^h being added to make the subtraction, thus :—

Time H.W., Devonport, July 7th		$0^h 15^m$ P.M.	(next tide) July 8th	$0^h 54^m$ A.M.
	+	12	Constant	— 0 46
		12 15	July 8th	0 8 A.M.
Constant for Falmouth	—	0 46		
Time H.W., Falmouth, July 7th		11 29 A.M.		

Here there is no P.M. tide on July 7th at Falmouth.

The following example shows the mode of procedure when the first tide is taken out for the last day of one month, and the second tide on the first day of the succeeding month.

Ex. 12. 1885, May 31st: find A.M. and P.M. times of high water at Ballycastle Bay.

The Standard Port for Reference is Belfast, and the Constant is — $4^h 18^m$. A blank (—) occurs in the morning column of May 31st at the Standard Port; there is, therefore, only an afternoon tide at that port on the 31st, and the Constant being *subtractive*, we use the *afternoon* time of high water at Belfast (increased by 12^h) to obtain the morning (A.M.) time of high water at Ballycastle Bay; and the next time of high water at Belfast, *i e.*, the time of high water at Belfast on the morning (A.M.) of June 1st must be employed to determine the P.M. tide at Ballycastle Bay. The work will stand as below :—

H.W., Belfast, May 31st		$0^h 4^m$ P.M.	(next tide) H.W., June 1st		$0^h 22^m$ A.M.
	+	12		+	12
		12 4			12 22
Constant	—	4 18	Constant	—	4 18
H.W., Ballycastle, May 31st		7 46 A.M.	H.W., May 31st		8 4 P.M.

When the Constant is subtractive, and the afternoon (P.M.) time of high water at the Standard Port is more than the Constant, but the morning (A.M.) tide less, there will only be an afternoon time of high water at the port required.

Ex. 13. 1885, November 1st: find A.M. and P.M. times of high water at Milford Haven (entrance).

The Standard Port for Reference is Pembroke, and the Constant — $0^h 16^m$ (see page 105, Admiralty Tide Tables). Constant *exceeds* Standard A.M. tide, therefore reject it; but it is less than P.M.; there is only a P.M. tide at Milford Haven.

Time H.W., Pembroke, Nov. 1st		$0^h 3^m$ A.M.		$0^h 44^m$ P.M.
Constant	—	16	—	16
				0 28 P.M.

No A.M. tide on November 1st at Milford Haven.

Ex. 14. 1885, July 7th: find A.M. and P.M. times of high water at Skull.

The Port for Reference for Skull is Queenstown, and the Constant is — $0^h 59^m$ (see page 104, Admiralty Tide Tables, 1885). Here the first tide at Queenstown occurs at $11^h 47^m$ A.M., and there is no afternoon (P.M.) tide that day, as a blank occurs in that column; but the next tide occurs July 8th, $0^h 21^m$ A.M., and since the Constant for Skull shows that the time of high water there takes place $0^h 59^m$ *earlier* than at Queenstown, that quantity *subtracted* from July 8^d $0^h 21^m$ A.M., will give a P.M. tide at Skull; therefore, use times of high water at Queenstown on the morning (A.M.) of July 7th and the morning A.M. of July 8th, thus :—

Queenstown, H.W., July 7th		$11^h 47^m$ A.M.	H.W., July 8th		$0^h 21^m$ A.M.
Constant	—	0 59		+	12
Skull, H.W., July 7th		10 48 A.M.			12 21
			Constant	—	0 59
			Skull, H.W., July 7th		11 22 P.M.

Ex. 15. 1885, August 27th: find A.M. and P.M. times of high water at Whitehaven.

The Standard Port for Reference is Liverpool, and the Constant — $0^h\ 9^m$ (Admiralty Tide Tables, page 105). In this example there is a blank in the morning column at Standard Port, we therefore take the afternoon tide, and the Constant being of the same value precisely as the time of high water, the result is a noon tide at Whitehaven.

(Only tide). Time H.W. Liverpool, Aug. 27th $0^h\ 9^m$ P.M.
Constant — 9

Time H.W. Whitehaven, Aug. 27th 0 0

There is only one high water on the 27th August, and this occurs at Noon.

Examples for Practice.

In each of the following examples it is required to find the time of high water A.M. and P.M.

1.	1885,	Jan. 11th,	Maryport.
2.	„	Feb. 2nd,	Cardigan.
3.	„	March 1st,	Hurst Camber.
4.	„	April 23rd,	Dunmore.
5.	„	May 3rd,	Lerwick
6.	„	June 19th,	Portland Bk'water.
7.	„	July 19th,	Ballycastle Bay.
8.	„	August 12th,	Boulogne.
9.	„	Sept. 2nd,	Wexford.
10.	„	Oct. 21st,	Cadiz.
11.	„	Nov. 27th,	Stromness.
12.	„	Dec. 19th,	Aberdeen.
13.	„	Jan. 6th,	Bordeaux.
14.	„	Feb. 10th,	Blyth.
15.	„	March 25th,	Penzance.
16.	1885,	March 25th,	Exmouth.
17.	„	Oct. 2nd,	Torbay.
18.	„	Oct. 11th,	Southampton.
19.	„	Oct. 18th,	Archachon.
20.	„	April 23rd,	Ballycotton.
21.	„	Dec. 13th,	Pwllheli.
22.	„	June 30th,	Lowestoft.
23.	„	August 1st,	Dieppe.
24.	„	April 23rd,	New Ross.
25.	„	July 7th,	Kilrush.
26.	„	Nov. 30th,	Sheephaven.
27.	„	August 4th,	Ilfracombe.
28.	„	Sept. 9th,	Inverary.
29.	„	June 23rd,	Belle Ile.
30.	„	June 5th,	Coleraine.

163. In pages 151 to 234 of Admiralty Tide Tables for 1885, are given the times of high water at full and change of a great number of ports, by which we are enabled to calculate approximately the time of high water on each day. The Constant is found by taking Brest as the Standard Port, at which place the time of high water, full and change, is $3^h\ 47^m$. The difference between the full and change at the given port and Brest will be the Constant to be employed (as in the preceding Rules), except there be a great difference of longitude, in which case the correction for the moon's meridian passage must be employed, since for the greatest longitude this correction may amount to half an hour. Should the longitude, however, not exceed 5°, it may be neglected, as doing so will scarcely make more than a difference of one minute. It must also be observed that the longitude of Brest is 4½° W. of Greenwich, and in strictness, therefore, in determining this correction 4° should be subtracted, if the longitude of the place be East, or added if it be West. The correction is found in Table XVI, Norie, or Table 28, Raper. Hence:

164. To find the time of high water at Foreign Ports whose Constants are not given in the Tide Tables.

RULE LXVIII.

1°. **To find the Constant.**—*In the* Alphabetical List of Ports *at the end of the* Admiralty Tide Tables for 1885, pages 191-234, *find the time of high water*, **Full and Change,** *at* Brest, *and also that corresponding* to the given port; subtract *the* less *from the* greater *of these two times, and the* remainder *will be the* Constant, **additive** if the full and change (F. & C.) *at the given port is* greater *than that of* Brest, *but* **subtractive** *if* less.

2°. *Take out the times of high water at* Brest *for the given day, and apply the Constant as directed in the preceding* Rule LXVII, pages 206-207; *the result is the time of high water* (nearly) *at the given place.*

3°. *Take out the longitude of* Brest *and also of the* given place; *take the sum if the* names *are* alike, *but take the* difference *if the* names *are* unlike.

4°. *Take out* (from the column to the left of those containing the times of high water at Brest) *the moon's transit for the* proposed day *and the following one, if the long. is West; but for the given day and the preceding one if the long. is East. Their* difference, *in either case, is the* Daily Variation, *or* Retardation.

5°. *Take from* Table 28, Raper, *or* Table 16, Norie, *the correction corresponding to the daily variation and longitude.*

6°. *Apply this correction by* addition *in* West *longitude, but by* subtraction *in* East *longitude, to the approximate times of high water already found,* the result is the times of high water on the proposed day at the given place.

Examples.

Ex. 1. 1885, October 16th: required the time of high water at Victoria River, Turtle Point (N.W. coast of Australia), longitude 130° E.

Time of H.W. full and change, Victoria River $7^h 15^m$ (p. 231)
„ „ Brest 3 47 (p. 196)
Constant + 3 28

☽'s transit, Oct. 16th, $6^h 29^m$ P.M.
15th, 5 42
47

Long. Victoria River 130° E.
„ Brest + 4 W.
126

Under 47^m and against 126° longitude, in Raper, Table 28, or Norie, 16, we find 15^m to be subtracted, because the longitude is E.

Time H.W. Brest, Oct. 16th $8^h 55^m$ A.M.
Constant + 3 28
12 23
Correction for longitude — 0 16
Time H.W. at Victoria River, Oct. 16th 12 7 A.M.
0 7 P.M.

Time H.W. Brest, Oct. 15th $8^h 23^m$ P.M.
Constant + 3 28
11 51 P.M.
— 0 16
Time H.W. at Victoria River, Oct. 15th 11 35 P.M.
No A.M. tide.

Ex. 2. 1885, January 21st: find the times of high water at Sandy Hook, long. 74° W.

Time of H.W. full and change, Sandy Hook $7^h 29^m$ (p. 225)
„ „ Brest 3 47 (p. 196)
Constant + 3 42

☽'s transit, Jan. 21st $4^h 4^m$
22nd 4 52
48

Long. Sandy Hook 74° W.
„ Brest + 4 W.
78

Under 48^m and against 78° in longitude, in Raper, Table 28, or Norie, 16, we find 10^m to be added, because the longitude is West.

Time H.W. Brest, Jan. 21st $6^h 39^m$ A.M.
Constant + 3 42
10 21 A.M.
Correction for longitude + 10
T. H.W. Sandy Hook, Jan. 21st 10 31 A.M.

Time H.W. Brest, Jan. 21st $6^h 59^m$ P.M.
Constant + 3 42
10 41 P.M.
Correction for longitude + 10
T. H.W. Sandy Hook, Jan. 21st 10 51 P.M.

Ex. 3. 1885, September 19th: required the times of high water at Rio Janeiro, longitude 43° 9′ W.

Time of H.W. full and change, at Rio Janeiro	$3^h\ 0^m$	(p. 223)
„ „ Brest	3 47	(p. 196)
Constant	— 0 47	

☽'s transit, Sept. 19th	$8^h 35^m$	Long. 43° W.	
20th	9 21	4	
	0 46	47	W.

Under 46^m and opposite 50° (nearest to Long. 47°) in Table XVI, Norie, or 28, Raper, stands the correction 6^m to be *added*.

Time H.W. Brest, Sept. 19th	$0^h 22^m$ P.M.		Time H.W. Brest, Sept. 20th	$0^h 54^m$ A.M.
Constant	— 0 47		Constant	— 0 47
	11 35 A.M.			0 7 A.M.
Correction for longitude	+ 6		Correction for longitude	+ 6
T. H.W. Rio Janeiro, Sept. 19th	11 41 A.M.		T. H.W. Rio Janeiro, Sept. 20th	0 13 A.M.

No P.M. tide.

Ex. 4. 1885, August 2nd: find the times of high water at Cape Virgin, Straits of Magellan, longitude 68° W.

Time of H.W. full and change, Cape Virgin	$8^h 30^m$	(p. 232)
„ „ Brest	3 47	(p. 196)
Constant	+ 4 43	

☽'s transit, August 2nd	$4^h 29^m$	48^m and long. 72° W. (68° + 4°) give corr. + 9^m.
3rd	5 17	
	48	

Time H.W. Brest, Aug. 2nd	$7^h 21^m$ A.M.		Time H.W. Brest, Aug. 1st	$6^h 59^m$ P.M.
Constant	+ 4 43		Constant	+ 4 43
	12 4 A.M.			11 42 P.M.
	0 4 P.M.		Correction for longitude	+ 9
Correction for longitude	+ 9		T. H.W. Cape Virgin, Aug. 1st	11 51 P.M.
T. H.W. Cape Virgin, Aug. 2nd	0 13 P.M.		No A.M. tide.	

Examples for Practice.

On the dates given, find times of high water at the undermentioned places.

1. 1885, August 1st: Nelson, New Zealand, longitude 173° E.
2. „ August 29th: Point de Galle, longitude 80° E.
3. „ April 10th: Caracus River, Ecuador, longitude 67° W.
4. „ February 28th: San Francisco, long. 122° W.
5. „ September 14th: Auckland Harbour, New Zealand, longitude 175° E.
6. „ August, 26th: Macao, longitude 114° E.
7. „ June 18th: Port Jackson, North Head, longitude 151° E.
8. „ December 1st: Yokohama, longitude 140° E.
9. „ June 8th, Avatska Bay, longitude 159° E.

GREENWICH DATE BY CHRONOMETER.

165. Def.—The Error of Chronometer on Mean Time at any place is the difference between the time indicated by the chronometer and the mean time at that place. **The error of chronometer on Mean Time at Greenwich** is the difference between the time indicated by the chronometer and the mean time at Greenwich. The error is said to be *fast* or *slow* as the chronometer is in advance of or behind the mean time at Greenwich.

166. Def.—Rate of Chronometer is the daily change in its error, or the interval it shows more or less than twenty-four hours in a mean solar day. If the instrument is going too fast, the rate is called *gaining;* if too slow, *losing*.

167. To find the Rate.—The rate of a chronometer is determined by comparing its errors for mean time, as found by observation at a given place, on different days. Thus, if by observation a chronometer is found 20^s *slow*, and at the end of ten days is found to be 50^s *slow* for mean time at the same place, it has evidently lost 30^s in ten days, whence its mean daily rate is 3^s *losing*. If on a given day chronometer be 12^s *fast*, and at the end of thirteen days 57^s *fast* for mean time at any place, it must have gained 45^s in thirteen days, or its rate is about $3^s{\cdot}5$ a day *gaining*. Hence the amount of the **daily rate** (supposed uniform) is found by the following

RULE LXIX.

Write one error under the other, then

Both *errors* **fast,** *or* **both slow,** *take their* difference.

One *error* **fast** *and the* **other slow,** *take their* sum.

Bring the sum *or* remainder *into seconds* (^{s}), *if not already expressed in seconds, and* divide *by the* number *of* days *between the dates of the two errors; the* result *will be the* daily rate *in seconds and tenths, or (perhaps) tenths only.*

168. To name the Rate.—*When the chronometer is* fast *either on Greenwich mean time, or on the time at place, if the error is* increasing, *the rate is* **gaining**; *if* decreasing, *the rate is* **losing.** *When the chronometer is* slow, *if the error is* increasing, *it is* **losing**; *if* decreasing, *it is* **gaining.** *When the chronometer is* fast, *and the error changes to* slow, *the rate is* **losing**; *if the error changes from* **slow** *to* **fast,** *the rate is* **gaining.**

EXAMPLES.

Ex. 1. A chronometer was $25^m\ 20^s$ *slow* for mean time at Greenwich on Nov. 20th, and on Nov. 30th was $24^m\ 45^s$ *slow* on Greenwich mean time: required the daily rate.

November 20th, chronometer	*slow*	$25^m 20^s$
November 30th, ,,	*slow*	24 45
Change of error in 10 days		35
Rate for 1 day		3·5 *gaining*.

In this example the chronometer is *slow* on November 20th, and *less slow* on November 30th, and the error is *decreasing*, therefore the chronometer is *gaining*.

Ex. 2. A chronometer was *slow* $28^{m}\ 5^{s}$ on mean time at Greenwich, Feb. 27th, 1880, and on March 11th was *slow* $29^{m}\ 36^{s}$ on mean time at Greenwich: find daily rate.

1880, February 27th, chronometer *slow*	$28^{m}\ 5^{s}$	Feb.	29 (leap year)
1880, March 11th, „ *slow*	29 36	Feb.	27
Change of error in 13 days	1 31		2
		March	11
	13)91(7^{s}·0		
	91	Int.	13^{d}

The error of chronometer, which is *slow*, is *increasing*, it is therefore *losing* 7^{s}·0.

Ex. 3. A chronometer was *fast* $1^{m}\ 23^{s}$ on mean time at Greenwich, June 2nd, and on July 1st was *fast* $1^{m}\ 37^{s}$·5 on mean time at Greenwich: find daily rate.

June 2nd, chronometer *fast*	$1^{m}23^{s}$	June	30
July 1st, „ *fast*	1 37·5	June	2
Change in 29 days	14·5		28
		July	1
	29)14·5(0·5		
	14·5	Int.	29^{d}

The error of chronometer is *fast* and *increasing*, hence the daily rate is 0^{s}·5 *gaining*.

Ex. 4. A chronometer was *fast* $1^{m}\ 51^{s}$ on mean time at Greenwich, May 1st, and on May 15th was 41^{s} *fast* on mean time at Greenwich: find daily rate.

May 1st, chronometer *fast*	$1^{m}51^{s}$	May	1
May 15th, „ *fast*	0 41	May	15
Change in 14 days	1 10	Int.	14
14 { 2	70		
7	35		
	5		

In this example the chronometer is *fast* and the error *decreasing*, the rate therefore is *losing*.

Ex. 5. July 28th, at 3^{h} P.M., the chronometer was $0^{m}\ 6^{s}$·0 *fast*, and on August 4th at same time, it was $0^{m}\ 17^{s}$·1 *slow*: required the daily rate.

July 28th, at 3^{h} P.M., chronometer *fast*	$0^{m}\ 6^{s}$·0
August 4th „ „ *slow*	0 17·1
Change of error in 7 days	23·1
Daily rate	3·3 *losing*.

In this example the error has changed from *fast* to *slow*, the chronometer therefore is *losing*.

Ex. 6. A chronometer was *slow* $1^{m}\ 4^{s}$ on mean time at Greenwich, March 1st, and on March 23rd, was $0^{m}\ 19^{s}$·6 *fast* on mean time at Greenwich: required the rate of chronometer.

March 1st, chronometer *slow*	$1^{m}\ 4^{s}$	March	23
March 23rd, „ *fast*	0 19·6	March	1
Change of error in 22 days	1 23·6	Int.	22^{d}
22 { 2	83·6		
11	41·8		
Rate	3·8 *gains*.		

In this example the error of chronometer has changed from *slow* to *fast*, it is evident, therefore, that the chronometer is *gaining*.

EXAMPLES FOR PRACTICE.

1. A chronometer was *slow* $2^m\,14^s$ on mean time at Greenwich, March 3rd, and on March 25th was *slow* $50^s{\cdot}4$ on mean time at Greenwich: find the daily rate.

2. A chronometer was *slow* $5^m\,19^s$ on mean time at Greenwich, January 30th, and on February 17th was *slow* $6^m\,13^s$ on mean time at Greenwich: find the daily rate.

3. A chronometer was $2^m\,2^s$ *fast* on mean time at Greenwich, January 24th, and on February 10th was *fast* $3^m\,18^s{\cdot}5$ for mean time at Greenwich: find the daily rate.

4. A chronometer was *slow* $49^s{\cdot}3$ on mean time at Greenwich, March 17th, and on April 1st was $1^m\,58^s{\cdot}7$ *fast* for mean time at Greenwich: find daily rate of chronometer.

5. A chronometer was *fast* $1^m\,4^s$ on mean time at Greenwich, January 10th, and on February 10th was $1^m\,6^s{\cdot}2$ *slow* for mean time at Greenwich: required the daily rate.

6. A chronometer was *fast* $1^m\,29^s$ on mean time at Greenwich, July 1st, and on July 23rd was *fast* $1^m\,5^s{\cdot}9$ on mean time at Greenwich: find daily rate.

7. A chronometer was *fast* 48^s on mean time at Greenwich, February 28th, and on March 15th was *slow* 48^s on mean time at Greenwich: find daily rate.

8. A chronometer was *slow* 20^s on mean time at Greenwich, September 1st, and on September 15th was *fast* $1^m\,18^s$ on mean time at Greenwich: find daily rate.

9. A chronometer was $1^m\,40^s$ *fast* on mean time at Greenwich, January 1st, and on February 20th was *correct* for Greenwich mean time: find the daily rate.

10. A chronometer was *correct* for Greenwich mean time on March 1st, and on April 20th was $0^m\,40^s$ *fast* on mean time at Greenwich: find daily rate.

169. To find the accumulated rate.—The accumulated rate may be found by decimals, thus:—

RULE LXX.

1°. *Affix two cyphers to the* hours, *and* divide *the result by* 6, *and the quotient by* 4 (*i.e.*, divide by 24); *the last quotient is the hours expressed as decimals of a day.*

2°. *Multiply the daily rate by the days and decimals of a day for which the accumulated rate is required, the* product *will be seconds* (^{s}). *Turn this product* (if above 60) *into minutes* (^{m}) *and seconds* (^{s}): the result is the accumulated rate.

EXAMPLES.

Ex. 1. A chronometer gains $2^s{\cdot}6$ in a day: what does it gain in $32^d\,16^h$?

$$24\left\{\begin{array}{r} 6)16{\cdot}00 \\ \hline 4)2{\cdot}66 \end{array}\right.$$

Prefixing the days to the decimals of a day. = 32·66

Rate 2·6

19596
6532

6,0)8,4·916

Accumulated rate $1^m\,24^s{\cdot}9$

Ex. 2. If a chronometer loses $9^s{\cdot}4$ in a day, what is its loss in $12^d\,9^h\,34^m = 12^d\,10^h$ (nearly)?

$$24\left\{\begin{array}{r} 6)10 \\ \hline 4)1{\cdot}66 \end{array}\right.$$

Prefixing the days to the decimals of a day. = 12·41

Rate 9·4

4964
11169

6,0)11,6·654

Accumulated rate $1^m\,56^s{\cdot}7$

or, $1^m\,57^s$

170. The **accumulated rate** may also be found thus:

EXAMPLES.

Ex. 1. If a chronometer gains $2^s\cdot6$ in a day, what will it gain in $32^d\ 16^h$?

$$\begin{array}{r|c|r}
12^h & \frac{1}{2}^d & 2^s\cdot6 \\
 & & 32 \\ \cline{3-3}
 & & 52 \\
 & & 78 \\
4 & \frac{1}{3} & 13 \\
 & & 4 \\ \hline
\multicolumn{2}{r|}{6,0} & 8,4\cdot9 \\ \cline{3-3}
\multicolumn{2}{r}{} & 1^m24^s\cdot9 \\ \cline{3-3}
\end{array}$$

or, 1^m25^s

Explanation.—Multiply the decimal $2^s\cdot6$ by the number of whole days, namely, 32. Next consider that 12 hours is the $\frac{1}{2}$ of 1 day, and 4 hours is the $\frac{1}{3}$ of 12 hours. 12 and 4 make up the whole number of hours, namely, 16. Divide the daily rate 2·6 by 2, which will give 1·3, the proportional part of rate in 12 hours; next divide 1·3 by 3, which gives the rate for 4 hours, $\frac{1}{3}$ of 12 hours (see example). Add the products and quotients together; the sum is $84^s\cdot9 = 1^m\ 24^s\cdot9$; and observe that the decimal is rejected, and since it is above ·5, therefore 1 is added to the seconds.

Ex. 2. If a chronometer loses $9^s\cdot4$ in a day, what will be the accumulated loss in $12^d\ 9^h\ 34^m$?

$12^d\ 9^h\ 34^m$ may be reckoned as $12^d\ 9^h\ 30^m$.

$$\begin{array}{r|c|r}
6^h & \frac{1}{4}^d & 9^s\cdot4 \\
 & & 12 \\ \cline{3-3}
 & & 112\cdot8 \\
3 & \frac{1}{2} & 2\cdot3 \\
30^m & \frac{1}{6} & 1\cdot1 \\
 & & 2 \\ \hline
\multicolumn{2}{r|}{6,0} & 11,6\cdot4 \\ \cline{3-3}
\multicolumn{2}{r}{} & 1^m56^s\cdot4 \\ \cline{3-3}
\end{array}$$

or, 1^m56^s

Explanation.—Multiply by 12; then 6 hours is $\frac{1}{4}$ of 1 day, and 3 hours $\frac{1}{2}$ of 6 hours, and 30 minutes is 1-6th of 3 hours. Divide the daily rate, $9^s\cdot4$, by 4, which will give 2·3, the proportional part of rate in 6 hours ($\frac{1}{4}$ of a day); next, divide 2·3 by 2, which gives the rate for 3 hours ($\frac{1}{2}$ of 6 hours); again, divide 1·1 by 6, which gives the change for 30 minutes (1-6th of 3 hours); then, add the product and several quotients together, the result is the accumulated rate for the interval.

171.—Before going to sea, the error of the chronometer on Greenwich mean time, and its daily rate, are supposed to have been accurately determined, either at an observatory by means of daily comparison with an astronomical clock, or by observations taken by a sextant at a place whose longitude is known.

172. When the **error** of a chronometer on Greenwich mean time, and also its **daily rate,** are known, we may determine Greenwich mean time at some other instant, as when an observation is taken, by the following

RULE LXXI.

1°. *Write down the time by chronometer, with the month and day before it;* under *this time write the* error *in the question,* adding *it if* slow, *rejecting* 24^h *if greater than* 24^h, *and putting the day one forward; but if the chronometer is* fast, subtract *the original error*, increasing *time shown by chronometer by* 24^h, *if necessary, and putting the day one back;* the result is the approximate Greenwich date.

NOTE.—When an error of the chronometer has been obtained at one date, and another error at a subsequent date, the interval between the two dates being known, a daily rate may be found by Rule LXIX.

2°. *Find the number of days and parts of a day to the nearest hour* elapsed *between the date of the error (second error if two are given) and the approximate date by chronometer.*

3°. *Multiply the daily rate of chronometer by the days and decimal parts of a day in the elapsed time,* found by No. 2°, *or by the* days elapsed, *and to the product* add *the proportional part for the fraction of a day, found by proportion, or by taking aliquot parts of a day for the hours of the same; the sum will be seconds* (^{s}), *which, if above* 60, *reduce to minutes* (^{m}), *and seconds* (^{s}), *and the result is the* accumulated rate, 4°. *To the approximate Greenwich date* (found by No. 1°) add *the* accumulated rate, *if chronometer is* losing, *but* subtract *if* gaining; *the* result *will be* mean time at Greenwich *at the instant of observation.*

EXAMPLES.

Ex. 1. 1887, Jan. 30th, P.M. at ship, time by a chronometer, Jan. $29^d\ 15^h\ 47^m\ 48^s{\cdot}3$, which was $9^m\ 19^s{\cdot}6$ *slow* for Greenwich mean time, Dec. 1st, 1886, and on Jan. 1st, 1887, was $10^m\ 24^s{\cdot}7$ *slow* on Greenwich mean time: required the Greenwich date by chronometer.

1886, Dec. 1st, *slow*	$9^m 19^s{\cdot}6$	Dec.	31 days.
1887, Jan. 1st, *slow*	10 24·7	Dec.	1
Change of error in 31 days	1 5·1		30
	60	Jan.	1
	31)65·1(2·1 *losing.*	Int.	31^d
	62		
	31		
	31		

The chronometer being *slow* and the error *increasing*, the rate must be marked *losing*.

Time by chron., Jan.	$29^d\ 15^h 47^m 48^s{\cdot}3$	Interval from	Daily rate			$2^s{\cdot}1$
Original error	+ 10 24·7	January 1st				28
Jan.	29 15 58 13·0	to January				168
Accumulated rate	+ 1 0·1	29th $15^h\ 58^m$				42
		is $28^d\ 16^h$ nly.		h	d	
Greenwich date, Jan.	29 15 59 13·1			12	½	58·8
				4	⅙	1·0
						·3
						6,0)6,0·1
			Acc. rate			$1^m\ 0^s{\cdot}1$

Ex. 2. 1887, March 21st, P.M. at ship, an observation was made when the time by chronometer was March $21^d\ 0^h\ 7^m\ 55^s$, which was $50^m\ 51^s$ *fast* on Greenwich mean time, November 22nd, 1886, and on December 21st, 1886, was *fast* $47^m\ 33^s{\cdot}8$ for mean noon at Greenwich: required the Greenwich date by chronometer.

November 22nd, chron. *fast*	$50^m 51^s{\cdot}0$	Nov.	30 days.
December 21st, *fast*	47 33·8	Nov.	22
Change of rate in 29^d	3 17·2		8
	60	Dec.	21
	29)197·2(6·8 *losing.*	Int.	29^d
	174		
	232		
	232		

The chronometer is *fast* and the *error decreasing*, the rate is therefore *losing*.

Time by chron., March	$21^d\ 0^h\ 7^m 55^s$	Dec.	31		Rate			$6^s{\cdot}8$
			21					89
or	20 24 7 55							
Original error	− 47 33·8		10					612
		Jan.	31					544
	23 20 21·2	Feb.	28			h	d	
Accumulated rate	+ 10 11·7	March	20	23		12	½	605·2
						8	⅓	3·4
Greenwich date, March	20 23 30 32·9	Int.	89	23		3	⅛	2·3
								·8
								6,0)61,1·7
					Acc. rate			10 11·7

In finding the accumulated rate, as the interval is within half an hour of 90 days ($23\frac{1}{2}$), we might have multiplied by 90, and deducted 1-48th ($\frac{1}{2}^h$ is 1-48th of a day) from the daily rate.

Ex. 3. Time by a chronometer, Sept. $8^d\ 0^h\ 13^m\ 28^s$, which was $0^m\ 47^s$ *slow* on Greenwich mean time, June 30th, and on July 12th, was $0^m\ 7^s$ *fast* on mean time at Greenwich.

June 30th, chron. *slow*	$0^m 47^s$	June	30^d
July 12th, „ *fast*	0 7		30
			—
Change in rate in 12 days	54		0
		July	12
Daily rate	4·5 *gaining*.		—
		Int.	12^d

In this instance the error of chronometer changes from *slow* to *fast*, the rate $4^s{\cdot}5$ is therefore to be marked *gaining*.

Time by chron., Sept.	$8^d\ 0^h 13^m 28^s$	July	31	Rate	$4^s{\cdot}5$
Original error	— 0 7		12		58
			—		—
Sept.	8 0 13 21		19		360
Accumulated rate	— 4 21	Aug.	31		225
		Sept.	8		—
Greenwich date, Sept.	8 0 9 0		—		6,0)26,1·0
		Int.	58		—
				Acc. rate	4 21·0

EXAMPLES FOR PRACTICE.

1. 1887, February 16th, A.M. at ship, an observation was taken, when the corresponding time by a chronometer was Feb. $16^d\ 7^h\ 59^m\ 25^s$, which was $20^m\ 23^s{\cdot}4$ *fast* on Greenwich mean time, December 1st, 1886, and on January 23rd, 1887, was $14^m\ 23^s$ *fast* on Greenwich mean time: required the Greenwich date by chronometer.

2. A chronometer showed April $29^d\ 5^h\ 0^m\ 0^s$, which was *fast* $33^m\ 30^s{\cdot}3$ on Greenwich mean time, March 19th, and on March 26th was $34^m\ 20^s$ *fast* for mean time at Greenwich: required the Greenwich date by chronometer.

3. A chronometer showed May $7^d\ 6^h\ 9^m\ 48^s$, which was *slow* $11^m\ 9^s{\cdot}4$ on Greenwich mean time, February 16th, and on February 26th was $11^m\ 41^s{\cdot}6$ *slow* for Greenwich mean time: required the Greenwich date by chronometer.

4. The chronometer showed June $25^d\ 20^h\ 59^m\ 53^s$, which was $0^m\ 33^s$ *fast* on Greenwich mean time, March 31st, and on April 15th was *correct* for mean time at Greenwich: required the Greenwich date by chronometer.

5. 1887, October 25th, P.M. at ship, time by chronometer Oct. $25^d\ 8^h\ 31^m\ 10^s$, which was $12^m\ 9^s{\cdot}2$ *slow* on Greenwich mean time, July 20th, and on August 13th was $10^m\ 2^s$ *slow* for Greenwich mean time: required the Greenwich date by chronometer.

6. Time by chronometer January $19^d\ 13^h\ 21^m\ 25^s$, which was $53^m\ 47^s$ *fast* on mean time at Greenwich, October 24th, and on October 31st, was $53^m\ 19^s$ *fast* for mean time at Greenwich: required the Greenwich date by chronometer.

7. Time by chronometer November $8^d\ 16^h\ 34^m\ 3^s$, which was $1^m\ 0^s$ *slow* on mean time at Greenwich, July 31st, and on August 12th was $0^m\ 2^s{\cdot}4$ *slow* on mean time at Greenwich.

8. Time by chronometer August $1^d\ 0^h\ 3^m\ 0^s$, which was $6^m\ 4^s$ *fast* on mean noon at Greenwich, May 31st, and on June 14th was $4^m\ 2^s{\cdot}2$ *fast* for Greenwich mean time.

9. Time by chronometer May $1^d\ 13^h\ 23^m\ 10^s$, chronometer *correct* for mean time at Greenwich, February 2nd, and on February 28th was $0^m\ 26^s{\cdot}0$ *slow* on Greenwich mean time.

10. Time by chronometer January $20^d\ 0^h\ 4^m\ 21^s$, which was 20^s *fast* on mean time at Greenwich, November 20th, 1886, and on December 10th, 1886, was 4^s *fast* on mean time at Greenwich: required the Greenwich date by chronometer.

11. Time by chronometer September $27^d\ 16^h\ 34^m\ 31^s$, which was $0^m\ 20^s$ *fast* on mean time at Greenwich, April 19th, and on May 9th was $0^m\ 18^s$ *slow* for Greenwich mean time: required the Greenwich date by chronometer.

12. Time by chronometer April $16^d\ 5^h\ 36^m\ 12^s$, which was $1^m\ 2^s$ *slow* for mean time at Greenwich, January 24th, and on February 28th was 29^s *fast* for Greenwich mean time.

173. When the "chronometer question" is given in a form similar to that below, we have to determine for ourselves the day of the month at Greenwich, that is, if the time shown by chronometer was 1^h, 2^h, 3^h, &c., on the civil or on the astronomical day; for, a frequent source of embarrassment in interpreting the indications of a chronometer arises from the division of its face into twelve instead of twenty-four parts, so that the same position of the pointer represents two periods of the day twelve hours distant. Thus, at 2^h past noon, and again at 14^h past noon the hands are in the same place, and it is necessary to determine whether it should be read as 2^h or 14^h, 5^h or 17^h, 6^h or 18^h past noon, and so on. To determine this point proceed according to this rule:—

RULE LXXII.

1°. *Get an approximate Greenwich date by means of the estimated ship mean time and the longitude by account* (Rule LVIII, page 179).

2°. *Proceed as directed in* Rule LXXI, page 218, *to apply the original error and accumulated rate to the time by chronometer.*

If the difference between Greenwich dates thus found by the two methods is nearly 12^h, then the Greenwich date by *chronometer*, found as above, must be increased by 12^h, and the *day put one back*, so as to make the two dates agree both in the day and hour nearly.

EXAMPLES.

Ex. 1. August 3rd, at about 3^h P.M., longitude by acct. 75° W., the chronometer marks $8^h\ 11^m\ 7^s$, and is $6^m\ 10^s$ *fast* on Greenwich mean time: what is the Greenwich astronomical date?

Approx. T. at ship, Aug.	$3^d\ 3^h\ 0^m$	Time by chron.	$8^h 11^m\ 7^s$
Longitude 75° W.	+ 5 0	Error of chron. *fast*	— 6 10
Approx. Green. date, Aug.	3 8 0	Green. date, Aug. 3rd	8 4 57

In this example the approximate Greenwich time is 8^h, it is evident that the chronometer must have shown 8^h from noon also.

Ex. 2. June 18th, at $10^h\ 52^m$ P.M., mean time at ship nearly, long. 60° W., an observation was taken, when a chronometer showed $2^h\ 48^m\ 40^s$, on June 6th its error was known to be $3^m\ 10^s{\cdot}2$ *fast* on Greenwich mean time, and its mean daily rate $3^s{\cdot}5$ *gaining:* required the mean time at Greenwich when the observation was taken.

Approx. Ship date, June	$18^d 10^h 52^m$	Interval from	Daily rate		$3^s{\cdot}5$
Longitude 60° W.	+ 4 0	June 6th to			12
		June 18th			—
Approx. Green. date	18 14 52	$14^h\ 52^m$ is	h	d	42·0
		$12^d\ 14^h\ 52^m$	12	½	1·7
		= $12^d\ 15^h$	3	⅛	·4
		nearly.			—
			Acc. rate		44·1

Chronometer showed		$2^h 48^m 40^s$
Original error		— 3 10·2 *fast*
		2 45 29·8
Accumulated rate		— 44·1 *gaining*
June	19^d	2 44 45·7 A.M.
	—	12 0 0
∴ Green. date, June	18	14 44 45·7

In this instance we see that 2^h by the chronometer must be reckoned at 14^h, that is, 12^h must be added to the indication of chronometer, and the day put one back.

TO FIND THE HOUR-ANGLE.

174. Given the true altitude of an object, its declination, and the latitude of the observer, to find the meridian distance or hour-angle.

RULE LXXIII.

1°. *Find the polar distance by* Rule LXI, page 187.

2°. *Add together the true altitude, latitude, and polar distance; take half their sum, and from the half sum subtract the true altitude, which call the remainder.*

3°. *Add together the secant of latitude, cosecant of polar distance, cosine of half sum, and sine of remainder; the sum of these logs. (rejecting* 10 *from the index), will be the log. of sun's hour-angle* (Table 31, Norie); *or sine square of sun's hour-angle* (Table 69, Raper).

When the polar distance exceeds 90°, take out the secant of reduced declination; or subtract the polar distance from 180°, and take the cosecant of the remainder. (See Rules XX and XXI, pages 53-54).

(a) *When both the latitude and declination are* 0, *take the true altitude from* 90°, *and so get the zenith distance, which convert into time by* Rule LVI, page 177, *or by* Table XIX, Norie, *or* Table 17, Raper: the result is the hour-angle.

The hour-angle can also be found without a special table, as follows:—Find the sum of the four logs., as above, and divide by 2: the result is the log. sine of *half* the hour-angle in *arc*. From the Table of log. sines find the arc corresponding thereto, which multiplied by 2, and converted into time (Rule LVI, page 177), is the hour-angle sought. It is thus evident that the complete solution may be obtained by means of the Table of log. sines, &c., alone.

Examples.

Correction for seconds (″).

The pol. dist. being greater than 90°, take the secant of decl. for the cosec. of pol. dist., and add the prop. part for 8″.

107° 9′ 0″	cosec. 0·019753	Diff. 65
Parts for 8	+ 5	8
107° 9′ 8″	cosec. 0·019758	5,20

Observation.—Always cut off *two figures* when working for seconds of arc.

81° 54′ 0″	cos. 9·148915	Diff. 1481
Parts for 54	— 800	54
81° 54′ 54″	cos. 9·148115	5924
		7405
		799,74

56° 31′ 0″	sine 9·921190	Diff. 139
Parts for 13	+ 18	13
56° 31′ 13″	sine 9·921208	417
		139
		18,07

Ex. 1. Given the true alt. 25° 23′ 41″, lat. 31° 17′ N., decl. 17° 9′ 8″ S., whence pol. dist. 107° 9′ 8″: find the hour-angle.

Altitude	25° 23′ 41″		
Latitude	31 17 0	sec.	0·068232
Polar dist.	107 9 8	cosec.	0·019758
	2)163 49 49		
	81 54 54	cos.	9·148115
	56 31 13	sine	9·921208
Hour-angle	= $2^h 58^m 11^s$	log.	9·15731,3
			15724
			7 = 1^s

Note.—In Norie, Table XXXI, the next less log. to 15731 is 15724, which gives $2^h\ 58^m\ 10^s$, and diff. 7 gives 1^s to add, whence the term corresponding to 9·15731 is $2^h\ 58^m\ 11^s$.

Ex. 2. Given the true altitude 40° 20′ 13″, latitude 30° 12′ N., red. decl. 23° 19′ 5″ N., whence polar dist. is 66° 40′ 55″: find the hour-angle.

66° 40′ 0″	cosec. 0·037055	Diff. 91
Parts for 55	— 50	55
66° 40′ 55″	cosec. 0·037005	455
		455
		50,05
68° 36′ 0″	cos. 9·562146	Diff. 537
Parts for 34	— 183	34
68° 36′ 34″	cos. 9·561963	2148
		1611
		182,58
28° 16′ 0″	sine 9·675390	Diff. 391
Parts for 21	+ 82	21
28° 16′ 21″	sine 9·675472	391
		782
		82,11

Altitude	40° 20′ 13″		
Latitude	30 12 0	sec.	0·063348
Polar dist.	66 40 55	cosec.	0·037005
Sum	137 13 8		
Half sum	68 36 34	cos.	9·561963
½ sum—alt.	28 16 21	sine	9·675472
Hour-angle	3h 42m 29s	log.	9·33778,8
			55
			24

In Norie, Table XXXI, we seek for the nearest log. to 9·33779, the nearest to which is 9·37755, which corresponds to 3h 42m 25s, then in column prop. parts we look for 24, which gives 4s to add; whence the hour-angle is 3h 42m 29s.

Ex. 3. Latitude 0°, declination 0°, true altitude 30°: required the hour-angle.

True altitude	30° 0′
	90 0
Zenith distance	60 0
	4
	6,0)24,0 0
Hour-angle	4h 0m 0s

Ex. 4. Given true altitude 75°, latitude 0°, declination 0°: find the hour-angle.

True altitude	75° 0′
	90 0
Zenith distance	15 0
	4
	6,c)6,0 0
Hour-angle	1h 0m 0s

Examples for Practice.

Required the hour-angle or meridian distance in each of the following examples:—

1.	True altitude	11° 21′ 29″	Latitude	30° 15′ S.	Declination	15° 21′ 4″ N.
2.	”	30 2 4	”	39 27 S.	”	5 48 23 N.
3.	”	27 48 22	”	40 10 N.	”	23 26 44 N.
4.	”	34 49 46	”	39 20 S.	”	21 15 7 S.
5.	”	25 38 11	”	0 29 N.	”	23 1 55 N.
6.	”	15 59 13	”	60 5 N.	”	7 25 38 S.
7.	”	29 2 27	”	0 0	”	0 0 0
8.	”	20 34 4	”	0 0	”	23 27 21 N.

LONGITUDE BY CHRONOMETER,

FROM AN OBSERVED ALTITUDE OF THE SUN.

175. The Longitude of a place may be determined by various methods, but that of a ship which is beyond sight of land can be ascertained astronomically only by what are called lunar observations, or by obtaining the mean time of the day or night from the observed altitude of a celestial body, and comparing it with the time shown by a chronometer which is supposed to express, at every instant, the mean solar time at Greenwich.

The principle on which the processes of the various methods of determining the longitude of a station are founded is the same in all cases, and consists in a determination of the time at Greenwich and at the place of ship at the same physical instant; the difference between those times being equal to the difference in longitude between Greenwich and the ship. This is obvious, for since apparent time at any place is expressed by the angle (in time) between the meridian of a place and a horary circle passing through the sun at the instant, the difference between the apparent times, and, consequently, between the mean times, at two places at the same instant must be equal to the angle in time between the meridians of the two places. Hence, the problem of finding longitude resolves itself into two distinct parts: 1st. The determination of the mean time at the station of the observer, and, 2nd. The determination of the mean time at the first meridian.

The observation of an altitude of a heavenly body enables us, with the assistance of other elements given in the Nautical Almanac—the declination and necessary corrections, and the known latitude—to compute the hour-angle of the body.

The body observed may be (1) the Sun, (2) the Moon, a Star, or a Planet —the moon furnishing the least reliable means of solving the problem.

The error of the chronometer on Greenwich mean time at a given date and its error being known, we thence find the Greenwich mean time corresponding to the instant when the observation is taken for determining the ship mean time; consequently, the mean time at ship having been obtained by an altitude of the sun, star, &c., the mere comparison of that time with the time indicated by chronometer will give the longitude of the ship. This is the most convenient and constant method of finding the longitude at sea.

176. In the following problem two chronometer *errors* are given, which, by means of the elapsed time, give a daily rate: hence proceed as follows:—

RULE LXXIV.

1°. *Write down the time by chronometer, with the month and day before it, under this time write the second error,* adding *if it is* slow, subtracting *if it is* fast.

2°. Next, *multiply the* daily rate *by the number of days and decimal parts of a day elapsed between the time at which the rate was* last *ascertained, and the* Greenwich *time.*

Turn this product into minutes and seconds.

(a) **Adding** *the result to the chronometer time* (found in 1° above) *when the rate is* losing.

(b) **Subtracting** *the result from the chronometer time* (found in 1° above) *when the rate is* gaining.

This will give the Greenwich mean time by the chronometer (see Rule LXXI, page 218).

3°. *Take out the sun's declination and the equation of time for the noon of Greenwich date, from page II of the month in the* Nautical Almanac, *and the corresponding hourly difference for each, from page I,* Nautical Almanac: *also take out the sun's semidiameter.*

4°. *Reduce the sun's declination and equation of time to the Greenwich time by correcting them for the mean time at Greenwich* (Rules LIX and LXII, pages 183 and 188).

5°. *Mark the corrected equation of time* "added to" *or* "subtracted from" *apparent time, as directed by the heading of the column of Eq. T. in page I of the month in the* Nautical Almanac.

6°. **For the Polar Distance.**—Subtract *the reduced declination from* 90°, *if* latitude *and* declination *of* same name; *but if of* different names add 90° *to declination.*

7°. **For the True Altitude.**—*Correct observed altitude for index error* (±), *dip* (—), (*refraction* (—), *parallax* (+), *or correction in altitude* (—), *and semidiameter* (+), *and thus get the true altitude* (Rule LXIII, page 192).

8°. *Find the hour-angle or meridian distance* (see Rule LXXIII, 2°, 3°).*

9°. *When the observation is made in the afternoon, that is, the question gives* P.M. *at ship, the hour-angle is* apparent time *past noon of the given day* at ship —*before which write the date at ship; but if the observation is made in the morning, that is, the question gives* A.M. *at ship, take the hour-angle from* 24^h, *the remainder is* apparent time at ship *reckoned from* noon *of the preceding day, the time at place in both instances being expressed in astronomical time.*

EXAMPLES.

Ex. 1. January 6th, P.M. at ship; suppose the sun's hour-angle to be $3^h\ 40^m\ 18^s$: what is the apparent time at ship?

Here the time being P.M., we have the ship date app. time, January $6^d\ 3^h\ 40^m\ 18^s$.

Ex. 2. January 6th, A.M. at ship; suppose the sun's hour-angle to be $3^h\ 40^m\ 18^s$: what is the apparent time at ship?

Here the hour-angle is	$3^h 40^m 18^s$
	24 0 0
Ship date app. T., Jan. 5th	20 19 42

---

* In finding longitude by chronometer the logs. used in finding the hour-angle are required to be taken out for seconds of arc.

Ex. 3. June 1st, P.M. at ship; suppose the hour-angle to be $3^h 54^m 39^s$: required the apparent time at ship.

Here the time being P.M., we have the app. time at ship, June $1^d 3^h 54^m 39^s$.

Ex. 4. June 1st; A.M. at ship; suppose the hour-angle to be $3^h 54^m 39^s$: what is the apparent time at ship?

Hour-angle	$3^h 54^m 39^s$
	24 0 0
App. T. at ship, May 31st	20 5 21

On comparing these examples with paragraph 9°, which they are intended to illustrate, the seaman will have no difficulty in understanding that, since the sun's Hour-angle is the Distance (in time) of the object from the meridian, if the observation is made in the afternoon (P.M.), as in Ex. 1, the time will be $3^h 40^m 18^s$ *past noon* of the 6th day; that is, the ship date (astronomical time) is January $6^d 3^h 40^m 18^s$—the astronomical day commencing always at noon; but if the observation be made in the morning (A.M.), the hour-angle will be the *time before noon* of the 6th day; or, as shown in Ex. 2, $20^h 19^m 42^s$ past noon of the day before—that is, January $5^d 20^h 19^m 42^s$. In Ex. 3, similarly, the observation being P.M., the time will be $3^h 54^m 39^s$ past noon of June 1st, while in Ex. 4, the observation being A.M., the time will be $3^h 54^m 39^s$ *before noon* of June 1st, *i.e.*, $20^h 5^m 21^s$ past noon, May 31st.

Obs.—In the new edition of NORIE's Tables the hour-angle is so arranged that when the observation is made P.M. at ship it is read from the top of the page; when A.M., from the bottom, using the next *greater* log. to the given one, and it will be the apparent time at ship, reckoning from the day before the ship date; in which case the necessity of deducting from 24^h (as explained in paragraph 9°) is obviated.

10°. *To apparent time at ship apply the reduced equation of time,* adding *or* subtracting as directed in page I, Nautical Almanac, *and so get mean time, which must be marked with the proper* **astronomical** day of the month.

11°. *Under ship mean time put Greenwich mean time*—not forgetting the day in each case:—*subtract the less from the greater; the remainder is longitude in time, which convert into arc*—degrees (°), minutes (′), and seconds (″); see Rule LVII, page 177, or Table 17, RAPER, or Table XIX, NORIE.

In taking the difference of Greenwich mean time and ship mean time, if the days of the month be different, it will be necessary to add 24 to the hours of the more advanced (that is, the one whose days are most), in order to enable the subtraction to be made.

12°. *Call the longitude* West *when Greenwich time is* greater *than ship mean time; but* East *when Greenwich mean time is least.*

The following examples illustrate this portion of the Rule:—

EXAMPLES.

EXAMPLE I.

Mean time at ship	Jan. $29^d 2^h 26^m 2^s$
Mean time at Green.	Jan. 29^d 6 26 47
Longitude in time	4 0 45
Longitude	60° 11′ 15″ W.

EXAMPLE II.

Mean time at ship	Feb. $28^d 16^h 20^m 45^s$
Mean time at Green.	Feb. 28^d 20 16 50
Longitude in time	3 56 5
Longitude	59°. 1′ 15″ W.

EXAMPLE III.

M.T. ship	May $20^d 5^h 44^m 3^s$
M.T. Green.	May 20^d 0 20 9
Longitude in time	5 23 54
Longitude	80° 58′ 30″ E.

EXAMPLE IV.

M.T. ship	July $2^d 20^h 26^m 53^s$
M.T. Green.	July 2^d 16 18 48
Longitude in time	4 8 5
Longitude	62° 1′ 15″ E.

Example V.

Suppose the date at ship deduced from the work to be March $6^d\ 5^h\ 3^m\ 38^s$ M.T., and the M.T. at Greenwich to be March $5^d\ 20^h\ 8^m\ 15^s$.

In this instance the ship date is *one day in advance* of Green. date, we therefore add 24^h to the ship date to enable us to make the subtraction.

M.T. at ship	March 6^d 5^h $3^m 38^s$
M.T. at Green.	March 5^d 20 8 15
Longitude in time	8 55 23
Longitude	133° 50′ 45″ E.

Example VI.

Suppose the date at ship deduced from the work to be August $8^d\ 17^h\ 20^m\ 10^s$ M.T., and the M.T. at Greenwich August $9^d\ 1^h\ 40^m\ 30^s$.

In this case 24^h must be added to the Green. date to enable us to make the subtraction, the *Green. date* being one day in advance of the ship date.

M.T. at ship	Aug. 8^d $17^h 20^m 10^s$
M.T. at Green.	Aug. 9^d 1 40 30
Longitude in time	8 20 20
Longitude	125° 5′ 0″ W.

Example VII.

Suppose the date at ship deduced from the work to be Jan. $31^d\ 21^h\ 10^m\ 42^s$, and the mean time at Green. to be February $1^d\ 8^h\ 50^m\ 48^s$.

In this instance the Green. date is *one day in advance* of ship date, we therefore add 24^h to Green. time to enable us to make the subtraction.

M.T. at ship	Jan. 31^d $21^h 10^m 42^s$
M.T. at Green.	Feb. 1^d 8 50 48
Longitude in time	11 40 6
Longitude	175° 1′ 30″ W.

Example VIII.

Suppose the date at ship is November $1^d\ 7^h\ 20^m\ 30^s$ M.T., and the date at Green. is Oct. $30^d\ 20^h\ 17^m\ 15^s$ M.T.

Here the 24^h must be added to the ship date to enable us to make the subtraction, the ship date being one day in advance of the Green. date.

M.T. at ship	Nov. 1^d $7^h 20^m 30^s$
M.T. at Green.	Oct. 30^d 20 17 15
Longitude in time	11 3 15
Longitude	165° 48′ 45″ E.

Note.—When the latitude at noon is given, the latitude in at the time of observation must be found by means of the course steered and distance sailed. The diff. of lat. *from noon* is to be named North or South, according as the ship at the time of observation is North or South of her latitude at noon. When the longitude is found, as in Exs. 1 to 6 (or according to paragraphs 11° and 12°, above), the diff. of long. between the ship at the time of observation and noon must be applied to find the longitude at noon. The diff. of long. is to be named East or West, according as the ship is East or West of its position at noon.

Examples.

Ex. 1. 1887, January 11th, P.M. at ship, latitude 49° 30′ N., the observed altitude sun's L.L. was 12° 20′ 30″, height of eye 18 feet, time by a chronometer January $11^d\ 6^h\ 44^m\ 36^s$ (being P.M. at Greenwich), which was $6^m\ 8^s{\cdot}3$ *fast* for mean noon at Greenwich, September 1st, 1886, and on September 30th, 1886, was $8^m\ 42^s$ *fast* on Greenwich mean time: required the longitude by chronometer.

Sept. 1st, chron. *fast*	6^m $8^s{\cdot}3$		Sept.	30
30th, „ *fast*	8 42·0		Sept.	1
Change in 29 days	2 33·7		Int.	29

29)153·7($5^s{\cdot}3$

T. by chron., Jan.	11^d	6^h	44^m	36^s
Original error		—	8	42
	11	6	35	54
Accumulated rate		—	9	7
Green date, Jan.	11	6	26	47

To find the interval from Sept. 30th, 1886, to Jan. 11th, 1887.

Sept.	30
	30
	—
	0
Oct.	31
Nov.	30
Dec.	31
Jan.	11
Int.	103^d

(a) Interval from Sept. 30th to Jan. 11th 6½^h is 103^d 6^h.

Daily rate			5^s·3
			103
			159
			530
	6	½	545·9
	½	$\frac{1}{12}$	1·3
			·1
			6,0)54,7·3
Acc. rate			9 7·3

Obs. alt. ☉'s L.L.	12°	20′	30″
Dip	—	4	4
	12	16	26
Refr. — 4′ 18″ } Par. + 9 }	—	4	9
	12	12	17
Semidiameter	+	16	18
True alt.	12	28	35

By *Raper's* Tables: dip — 4′ 10″, refr. — 4′ 23″, par. + 9″, semid. + 16′ 18″, and true alt. 12° 28′ 24″.

Decl., page II, N.A.					H.D.
Jan. 11th, noon	21°	48′	35″	S. *decr.*	23″·49
Correction	—	2	32		6·45
Red. decl.	21	46	3	S.	11745
					9396
Polar dist.	111	46	3		14094
					6,0)15,1·5105
					Corr. — 2 31·5

Eq. T., page II, N.A.			H.D.
Jan. 11th, noon	8^m 8^s·4	*incr.*	0^s·983
Correction	+ 6·3		6·45
Red. Eq. T.	8 14·7		4915
To be *added* to A.T.			3932
			5898
			6·34035

Altitude	12°	28′	35″		
Latitude	49	30	0	sec.	0·187456
Polar dist.	111	46	3	cosec.	0·032127
Sum	173	44	38		
Half sum	86	52	19	cos.	8·736936
Remainder	74	23	44	sine	9·983690
Hour-angle	2^h	17^m	21^s	log.	8·940209

App. T. at ship,	Jan.	11^d	2^h	17^m	21^s
Eq. time		+		8	15
M.T. ship,	Jan.	11	2	25	36
M.T. Green.,	Jan.	11	6	26	47
Long. in time			4	1	11

Longitude 60° 17′ 45″ W.

By *Raper:* Log. sine sq. (sum of logs.) 8·940440 gives hour-angle 2^h 17^m 23^s, *long.* 60° 17′ 15″ W.

The observation having been made in the afternoon (P.M.) at ship, the hour-angle 2^h 17^m 21^s will be 2^h 17^m 21^s *past noon* of the 11th day, that is, the apparent time at ship (astronomical time) is January 11^d 2^h 17^m 21^s (see Rule LXXIV, 9°, page 225).

Ex. 2. 1887, May 20th, P.M. at ship, latitude 50° 43′ N., obs. alt. sun's L.L. 17° 10′, index corr. — 1′ 39″, height of eye 28 feet, time by a chronometer May 20^d 0^h 19^m 53^s (or 0^h 19^m 53^s P.M.), which was 33^s *fast* on mean noon at Greenwich, March 20th, and on April 1st was 23^s·4 *fast* on Greenwich mean time.

March	31
	20
	—
	11
April	1
	—
Int.	12^d

March 20th, chron. *fast*	0^m 33^s
April 1st „ *fast*	0 23·4
Change in 12 days	12)9·6
Daily rate	0·8 *losing.*

April	30
	1
	—
	29
May	20
	—
Int.	49^d

T. by chron., May	$20^d\ 0^h19^m53^s$
Original error *fast*	— 23·4
	0 19 29·6
Accumulated rate	+ 39·2
Green. date, May	20 0 20 9

Interval from April 1st to May 20th is 49^d.*

Rate	0^s·8
Interval	× 49
Acc. Rate	39·2

Obs. alt. ☉'s L.L.	17° 10′ 0″
Index corr.	— 1 39
	17 8 21
Dip	— 5 5
	17 3 16
Corr. alt.	— 2 55
	17 0 21
Semidiameter	+ 15 50
True alt.	17 16 11

By *Raper:* Dip — 5′ 10″, refr. — 3′ 9″, par. + 8″, semid. + 15′ 50″, true alt. 17° 16′ 0″.

H. diff., May 20th	+ 31″·36	H. diff., May 20th	— 0^s·134
$20^m \mid \frac{1}{3}^h \mid$	31·36	$20^m \mid \frac{1}{3}^h \mid$	0·134
Correction	+ 10·45	Correction	— ·045
Decl., May 20th, noon	19 58 15 N. *incr.*	Eq. Time, May 20th, noon	3^m42^s·90
Red. decl.	19 58 25 N.	Red. Eq. time	3 42·85
	90		(To be *subtracted* from A.T.)
Polar dist.	70 1 35		

Altitude	17° 16′ 11″		
Latitude	50 43 0	sec.	0·198489
Polar dist.	70 1 35	cosec.	0·026941
	138 0 46		
Half sum alt.	69 0 23	cos.	9·554203
	51 44 12	sin.	9·894965
Hour-angle	$5^h47^m29^s$	log.	9·674598

App. T. Ship, May 20th	$5^h47^m29^s$
Eq. Time	— 3 43
Mean T. Ship, May 20th	5 43 46
Mean T. Green., May 20th	0 20 9
Long. in time	5 23 37
Longitude	80° 54′ 15″ E.

By *Raper:* Log. sine sq. (sum of logs.) 9·674640 gives hour-angle $5^h\ 47^m\ 31^s$, long. 80° 54′ 45″ E.

Since the sun's hour-angle is the distance (time) of the object from the meridian, and the observation is P.M. in this example, the time (or hour-angle) will be $5^h\ 47^m\ 29^s$ *past noon* of the 20th day; hence the app. time at ship is May $20^d\ 5^h\ 47^m\ 29^s$ (see Rule LXXIV, 9°, page 225).

Ex. 3. 1887, July 3rd, A.M. at ship, latitude 32° 10′ S., obs. alt. sun's L.L. 14° 10′ 15″, index. corr. + 1′ 22″, height of eye 19 feet, time by a chronometer July $2^d\ 16^h\ 33^m\ 22^s$ (being $3^d\ 4^h\ 33^m\ 22^s$ A.M. at Greenwich), which was $17^m\ 16^s$·4 *fast* for Greenwich mean noon, May 16th, and on June 1st was $16^m\ 22^s$ *fast* for mean time at Greenwich: required the longitude.

May	31 days.
	16
	15
June	1
Int.	16

May 16th, Chronometer	*fast*	17^m16^s·4
June 1st, „	*fast*	16 22·0
Change in 16 days		54·4
Daily rate		3·4 *losing.*

June	30 days.
	1
	29
July	$2\ 16^h$
and Int	31 16

T. by chron., July	$2^d\ 16^h33^m22^s$
Original error	— 16 22
July	2 16 17 0
Accumulated rate	+ 1 48
Green. date, July	2 16 18 48
Time before noon	3 7 41
or,	7·7

Decl. and Eq. of Time are taken out of *Nautical Almanac* for the *nearest* noon to Green. date and corrected *back.*

Interval from June 1st to July 2nd 16^h is $31^d\ 16^h$.

Daily rate	3^s·4
Interval	31
	34
	102
$12 \mid \frac{1}{2} \mid$	1054
$4 \mid \frac{1}{3} \mid$	17
	6
	6,0)10,7·7
Acc. rate	1 47·7

Obs. alt. ☉'s L.L.	14° 10′ 15″
Index corr.	+ 1 22
	14 11 37
Dip	— 4 11
	14 7 26
Corr. alt.	— 3 35
	14 3 51
Semidiameter	+ 15 46
True alt.	14 19 37

By *Raper:* Index corr. + 1′ 22″, dip — 4′ 15″, refr. — 3′ 48″, par. + 8″, semid. + 15′ 46″, true alt. 14° 19′ 28″.

Decl., page II, N.A.		H.D.
July 3rd, noon	22° 58′ 50″ N. *decr.*	+ 11″·99
Correction	+ 1 32	7·7
Red. decl.	23 0 22 N.	8393
	90	8393
Polar dist.	113 0 22	6,0)9,2·323
	Corr.	+ 1 32

Eq. T., page II, N.A.		H.D.
3rd, noon, *add*	3^{m}53^s·0	+ 0^s·458
Correction	− 3·5	× 7·7
Red. Eq. Time	3 49·5	3206
		3206
(To be *added* to A.T.)	Corr.	+ 3·5266
	or,	3·5

Altitude	14° 19′ 37″		
Latitude	32 10 0	sec.	0·072371
Polar dist.	113 0 22	cosec.	0·035994
	159 29 59		
	79 44 59	cos.	9·250294
	65 25 22	sine	9·958756
Hour-angle	3^{h}36^{m}54^s	log.	9·317415
A.T. ship, July 2^d	20 23 6		

App. Time ship, July 2nd	20^{h}23^m 6^s
Eq. Time	+ 3 50
Mean time ship, July 2nd	20 26 56
Mean time Green, July 2nd	16 18 48
Longitude in time	4 8 8
Longitude	62° 2′ 0″E.

By *Raper:* Log. sine sq. 9·317467 gives hour-angle 3^h 36^m 55^s, long. 62° 1′ 45″ E.

In this example the time of observation is A.M. at ship, the hour-angle is therefore the time *before noon* of July 3rd, and as all calculations are made in the astronomical day, we take the hour-angle from 24^h, the remainder is A.T. at ship, reckoned from *noon* of the *preceding day*, viz, that of July 2nd. Since the observation is made in the forenoon at ship we may take the hour-angle from the bottom of the table, and the time so found is A.T. at ship, reckoned from noon of the preceding day. (See Rule LXXIV, page 225.)

Ex. 4. 1887, April 14th, A.M. at ship, latitude 52° 10′ N., observed altitude sun's L.L. 18° 20′ 25″, index correction + 55″, height of eye 12 feet, time by chron. 14^d 5^h 5^m 5^s (being P.M. at Greenwich, which was *fast* 5^m 52^s·4 for mean noon at Greenwich, February 13th, and on February 25th was *fast* 6^m 38^s for mean noon at Greenwich.

February 13th, chronometer	*fast*	5^m 52^s·4
February 25th, „	*fast*	6 38
Int. 12		12) 45·6
		3·8 *gaining*.

Feb.	28^d
	25
	3
March	31
April	14 5^h
Int.	48^d 5^h*

T. by chron., Ap.	14^d 5^h 5^m 5^s
Original error	− 6 38
	14 4 58 27
Accumulated rate	− 3 3
Green. date, April	14 4 55 24
or	4^h·9

By *Raper:* Index corr. + 55″, dip − 3′ 20″, refr. − 2′ 55″, par. + 8″, semid. + 15′ 58″, true alt. 18° 31′ 11″.

* Interval from Feb. 25th to April 14th 5^h, is 48^d 5^h.

Rate		3^s·8
Interval		48
4	⅙	182·4
1	¼	·6
		·1
		6,0)18,3·1
		3 3·1

Obs. alt. ⊙'s L.L.	18° 20′ 25″
Index corr.	+ 55
	18 21 20
Dip	− 3 19
	18 18 1
Corr. alt.	− 2 42
	18 15 19
Semid.	+ 15 58
True alt.	18 31 17

Decl., page II, N.A.		H.D.
Ap. 14th, noon	9° 23′ 36″ N. *incr.*	+ 53″·98
Correction	+ 4 25	× 4·9
Red. decl.	9 28 1 N.	6,0)26,4·502
Polar dist.	80 31 59	+ 4 25 corr.

Eq. T., page II, N.A.		H.D.
14th, noon, *add*	0^{m}17^s·88 *decr.*	0^s·634
Correction	− 3·11	× 4·9
Red. Eq. T.	0 14·77	3·1066
(To be *added* to A.T.)		

Altitude	18° 31′ 17″		
Latitude	52 10 0	sec.	0·212280
Polar dist.	80 31 59	cosec.	0·005955
	151 13 16		
	75 36 38	cos.	9·395346
	57 5 21	sine	9·924030
Hour-angle	$4^{h}47^{m}41^{s}$	log.	9·53761,1
	24		57
A.T.S. April 13^{d}	19 12 19		4

App. T. ship, April	$13^{d}\,19^{h}\,12^{m}\,19^{s}$
Eq. Time	+ 15
Mean T. ship, April	13 19 12 34
Mean T. Green., April	14 4 55 24
Longitude in time	9 42 50
Longitude	145° 42′ 30″ W.

By *Raper:* Log. sine sq. 9·537640 gives hour-angle $4^{h}\,47^{m}\,42^{s}$, long. 145° 42′ 45″ W.

The observation having been made A.M. at ship, the hour-angle is the time *before noon* at ship, viz., that of April 14th; therefore take the hour-angle from 24^{h}, and the remainder is apparent time at ship, reckoned from the preceding noon, April 13th; or if the hour-angle is taken from the bottom of the table (it being A.M. at ship) it is the apparent time—April $13^{d}\,19^{h}\,12^{m}\,19^{s}$—reckoning from the preceding noon at ship. The Greenwich and ship dates being different (the Greenwich date being the greater, or in advance of ship date), therefore subtract the latter from the former (borrowing 24^{h} to enable the subtraction to be made).

Ex. 5. 1887, June 15th, P.M. at ship, latitude 13° 54′ S., obs. alt. sun's L.L. 16° 16′ 16″, index corr. + 0′ 16″, height of eye 16 feet, time by a chronometer $14^{d}\,22^{h}\,1^{m}\,22^{s}$, which was $1^{m}\,17^{s}$ *slow* for mean noon at Greenwich, April 1st, and on April 16th was $1^{m}\,22^{s}$ *fast* on mean time at Greenwich.

April 1st, chron. *slow*		$1^{m}17^{s}$
16th, „ *fast*		1 22
Change in 15 days		2 39
	Daily rate	$10^{s}{\cdot}6$ *gaining.*

$2^{m}39^{s}$
60
15)159(10ˢ·6
15
90
90

April	30^{d}
	16
	14
May	31
June	14 22^{h}
Int.	$59^{d}\,22^{h}$*

T. by chron., June	$14^{d}\,22^{h}\,1^{m}\,22^{s}$
Original error	— 1 22
	14 22 0 0
Accumulated rate	— 10 35
Green. date, June	14 21 49 25
T. *from* noon, June	15 2 11

By *Raper:* Index corr. + 0′ 16″, dip — 4′ 0″, refr. — 3′ 19″, par. + 8″, semid. + 15′ 47″, true alt. 16° 25′ 8″.

(Decl. is taken out for nearest noon to Green. date and corrected *back.*)

* Interval from April 16th to June 14th 22^{h}, is $59^{d}\,22^{h}$.

Daily rate		$10^{s}{\cdot}6$
Interval		59
		954
		530
12	½	625·4
8	⅓	5·3
2	¼	3·5
		·9
		6,0)63,5·1
		10 35·1

Obs. alt. ☉'s L.L.	16° 16′ 16″
Index corr.	+ 0 16
	16 16 32
16 feet	— 3 50
	16 12 42
Corr. alt.	— 3 5
	16 9 37
Semidiameter	+ 15 47
True alt.	16 25 24

(Eq. T. is taken out for nearest noon to Green. date and corrected *back.*)

Decl., page II, N.A.		H.D.
June 15th, noon	23° 18′ 58″·5 N. +	6·47
Correction	— 14 ·2	2·2
Red. decl.	23 18 44 N.	1294
		1294
Polar dist.	113 18 44	14·234

Eq. T., page II, N.A.		H.D.
15th, noon	*add* $0^{m}\,7^{s}{\cdot}0$ +	+ 0·530
Correction	— 1 ·1	× 2^{h}
Red. Eq. T.	0 5 ·9	1·060

(To be *added* to A.T.)

Altitude	16°25′ 24″		
Latitude	13 54 0	sec.	0·012908
Polar dist.	113 18 44	cosec.	0·036986
	143 38 8		
Half sum alt.	71 49 4	cos.	9·494210
	55 23 40	sine	9·915443
Hour-angle	$4^h 19^m 42^s$	log.	9·45954,7
			44
		2^s =	11

Ap. T. ship, June	$15^d\ 4^h 19^m 42^s$
Eq. Time	+ 0 6
Mean T. ship, June	15 4 19 48
Mean T. Green., June	14 21 49 25
Long. in time	6 30 23
Longitude	97°35′ 45″ E.

By *Raper:* Log. sine sq. 9·459610, hour-angle $4^h\ 19^m\ 43^s$, long. 97° 36′ 0″ E.

In this example the observation is made P.M : hence the hour-angle is apparent time at ship, before which we write the date at ship, viz , June 15th, (see head of question); and since the mean time at ship is June 15th $4^h\ 19^m\ 48^s$, which is in advance of mean time at Greenwich, the latter being June $14^d\ 21^h\ 49^m\ 25^s$, we subtract mean time at ship from mean time at Greenwich, and 24^h is borrowed in subtracting.

Ex. 6. 1887, June 23rd, P.M. at ship, latitude 0°, observed altitude sun's L.L. 20° 25′, height of eye 20 feet, time by chronometer June $23^d\ 5^h\ 52^m\ 9^s$, which was *fast* $0^m\ 40^s$ on Greenwich mean time, April 6th, and on May 1st was $0^m\ 30^s$ *slow* for mean noon at Green.

Interval from April 6th to May 1st is 25 days; the change in rate in that time is 70^s ($0^m\ 40^s$ *fast* + $0^m\ 30^s$ *slow* = 70^s): then 70^s ÷ 25 = $2^s{\cdot}8$ *losing*.

T. by chron., June	$23^d\ 5^h 52^m\ 9^s$
Original error	+ 30
June	23 5 52 39
Accumulated rate	+ 2 29
Green. date, June	23 5 55 8

By *Raper:* dip − 4′ 20″, refr. − 2′ 36″, par. + 8″, semid. + 15′ 46″, and true alt. 20° 33′ 58″.

Interval from May 1st to June 23rd 6^h, is $53^d\ 6^h$.

Daily rate	$2^s{\cdot}8$
Interval	53
6 | ¼ |	148·4
	·7
	6,0)14,9·1
	2 29·1

Obs. alt. ⊙'s L.L.	20°25′ 0″
Dip	− 4 17
	20 20 43
Corr. alt.	− 2 25
	20 18 18
Semidiameter	+ 15 46
True altitude	20 34 4

Decl., page II, N.A.		H.D.
June 23rd, noon	23°26′ 29″ N. −	1·79
Correction	− 11	5·9
Red. decl.	23 26 18	1611
		895
Polar dist.	66 33 42	10·561
	or 113 26 18	

Eq. T., page II, N.A.		H.D.
23rd, noon	$1^m 51^s{\cdot}2$ +	·542
Correction	+ 3 ·2	5·9
Red. Eq. T.	1 54 ·4	4878
		2710
(*Added* to A.T.)		3·1978

The lat. being 0° we may either take the decl. *from* 90° or *add* 90° to the decl. for the pol. dist.

Altitude	20°34′ 4″		
Latitude	0 0 0	sec.	0·000000
Polar dist.	66 33 42	cosec.	0·037399
	87 7 46		
	43 33 53	cos.	9·860096
	22 59 49	sine	9·591823
Hour-angle	$4^h 29^m 57^s$	log.	9·48931,8
Eq. time	+ 1 54		
M.T. ship	23^d 4 31 51		
M.T.G.	23^d 5 55 8		
Long. in time	1 23 17		
Longitude	20°49′ 15″ W.		

Altitude	20°34′ 4″		
Latitude	0 0 0	sec.	0·000000
Polar dist.	113 26 18	cosec.	0·037399
	134 0 22		
	67 0 11	cos.	9·591823
	46 26 7	sine	9·860096
Hour-angle	$4^h 29^m 57^s$	log.	9·48931,8
Eq. time	+ 1 54		
M.T. ship	23^d 4 31 51		
M.T.G.	23^d 5 55 8		
Long. in time	1 23 17		
Longitude	20°49′ 15″ W.		

By *Raper* the answer comes out the same.

EXAMPLES FOR PRACTICE.

1. 1887, January 2nd, A.M. at ship, latitude 36° 59′ S., observed altitude sun's L.L. 49° 10′, index correction — 2′ 40″, height of eye 14 feet, time by a chronometer $1^d\ 19^h\ 8^m\ 50^s$ (being $7^h\ 8^m\ 50^s$ A.M. at Greenwich), which was *slow* $18^m\ 2^s$ for mean noon at Greenwich, November 30th, 1886, and on December 7th, 1886, was $19^m\ 10^s{\cdot}6$ *slow* for mean time at Greenwich: required the longitude.

2. 1887, February 19th, A.M. at ship, latitude 38° 18′ S., observed altitude sun's L.L. 21° 30′ 40″, index correction — 6′ 45″, height of eye 14 feet, time by a chronometer $18^d\ 19^h\ 53^m\ 37^s{\cdot}6$ (being $7^h\ 53^m\ 37^s{\cdot}6$ A.M. at Greenwich), which was $4^m\ 16^s{\cdot}6$ *fast* for mean noon at Greenwich, January 23rd, and on January 30th was $5^m\ 9^s{\cdot}8$ *fast* for mean time at Greenwich.

3. 1887, March 28th, P.M. at ship, latitude 20° 19′ S., observed altitude sun's L.L. 30° 14′, index correction — 2′ 10″, height of eye 30 feet, time by chronometer $28^d\ 0^h\ 10^m$ (being $0^h\ 10^m$ P.M. at Greenwich), which was $54^m\ 48^s$ *fast* for mean noon at Greenwich, October 20th, 1886, and on December 2nd, 1886, was $51^m\ 56^s$ *fast* for mean noon at Greenwich.

4. 1887, April 15th, A.M. at ship, latitude 53° 5′ N., observed altitude sun's L.L. 16° 8′ 40″, index correction — 40″, height of eye 15 feet, time by a chronometer $15^d\ 6^h\ 18^m\ 49^s$ (being P.M. at Greenwich), which was $0^m\ 4^s{\cdot}4$ *slow* for mean noon at Greenwich, February 11th, and on March 11th was $2^m\ 38^s$ *fast* for mean noon at Greenwich.

5. 1887, May 19th, P.M. at ship, latitude 2° 58′ S., observed altitude sun's L.L. 30° 30′, index correction + 52″, height of eye 19 feet, time by chronometer $19^d\ 0^h\ 23^m\ 58^s$, which was 28^s *fast* for mean noon at Greenwich, January 3rd, and on January 31st was 42^s *slow* on mean time at Greenwich.

6. 1887, June 15th, A.M. at ship, latitude 12° 11′ N., observed altitude sun's L.L. 39° 39′ 40″, index correction + 20″, height of eye 17 feet, time by a chronometer $14^d\ 17^h\ 59^m\ 30^s$ (being $5^h\ 59^m\ 30^s$ A.M. at Greenwich), which was *slow* $5^m\ 56^s{\cdot}3$ for mean time at Greenwich, April 20th, and on May 12th was $2^m\ 29^s{\cdot}5$ *slow* for mean noon at Greenwich.

7. 1887, July 5th, A.M. at ship, latitude 23° 48′ N., observed altitude sun's L.L. 48° 36′ 50″, index correction — 50″, height of eye 17 feet, time by chronometer $5^d\ 0^h\ 42^m\ 38^s$ (being $0^h\ 42^m\ 38^s$ P.M. at Greenwich), which was *fast* $4^m\ 47^s{\cdot}8$ for mean noon at Greenwich, May 6th, and on June 1st was *fast* $6^m\ 50^s$ for mean noon at Greenwich.

8. 1887, August 13th, A.M. at ship, latitude 30° 46′ S., observed altitude sun's L.L. 27° 15′, index correction — 1′ 15″, height of eye 21 feet, time by a chronometer $13^d\ 2^h\ 0^m$ (being $2^h\ 0^m$ P.M. at Greenwich), which was *slow* $26^m\ 7^s{\cdot}6$ for mean noon at Greenwich, April 10th, and on May 1st was *slow* $25^m\ 13^s$ for mean noon at Greenwich.

9. 1887, September 1st, P.M. at ship, latitude 35° 49′ N., observed altitude sun's L.L. 44° 32′ 10″, index correction + 1′ 46″, height of eye 20 feet, time by chronometer August $31^d\ 19^h\ 24^m\ 57^s$ (being $7^h\ 24^m\ 57^s$ A.M. at Greenwich), which was *fast* $11^m\ 57^s{\cdot}4$ for mean noon at Greenwich, July 3rd, and on July 31st was *fast* $12^m\ 17^s$ for mean noon at Greenwich.

10. 1887, October 25th, P.M. at ship, latitude 51° 30′ S., observed altitude sun's L.L. 40° 22′, index correction — 1′ 50″, eye 20 feet, time by chronometer $25^d\ 8^h\ 22^m\ 1^s$ (or $8^h\ 22^m\ 1^s$ P.M.), which on July 20th was *slow* $21^m\ 19^s$ for mean noon at Greenwich, and *gaining* $4^s{\cdot}7$ daily.

11. 1887, November 27th, A.M. at ship, latitude 39° 20′ S., observed altitude sun's L.L. 34° 37′ 55″, index correction + 1′ 15″, eye 18 feet, time by a chronometer $27^d\ 7^h\ 41^m\ 30^s$ (being P.M. at Greenwich), which on November 9th was $29^m\ 40^s$ *fast* on mean noon at Greenwich, and *losing* $6^s{\cdot}7$ daily.

12. 1887, December 25th, A.M. at ship, latitude 9° 59′ S., observed altitude sun's L.L. 10° 38′ 45″, index correction — 3′ 12″, eye 18 feet, time by a chronometer $24^d\ 18^h\ 6^m$ (being A.M. at Greenwich) which was *slow* $4^m\ 20^s{\cdot}4$ for mean noon at Greenwich, July 1st, and on July 29th showed mean noon at Greenwich.

13. 1887, January 1st, P.M. at ship, latitude 38° 28′ S., observed altitude sun's L.L. 39° 0′, index correction — 2′ 25″, eye 12 feet, time by chronometer $1^d\ 11^h\ 58^m\ 29^s$ (being P.M. at Greenwich), which was *slow* $1^h\ 49^m\ 19^s$ for mean noon at Greenwich, September 12th, 1886, and on October 13th was $1^h\ 52^m\ 53^s$ *slow* for mean noon at Greenwich.

14. 1887, February 11th, A.M. at ship, latitude 53° 12′ N., observed altitude sun's L.L. 12° 10′, index correction — 49″, eye 12 feet, time by chronometer $10^d\ 22^h\ 22^m\ 22^s$ (being A.M. at Greenwich), which was *fast* $34^m\ 41^s{\cdot}7$ for mean noon at Greenwich, October 31st, and on December 1st, 1886, was *fast* $38^m\ 59^s$ for mean noon at Greenwich.

15. 1887, October 26th, A.M. at ship, latitude 28° 10′ N., observed altitude sun's U.L. 25° 32′ 20″, index correction 0″, eye 17 feet, time by chronometer $0^h\ 24^m\ 6^s$ (being P.M. at Greenwich), which was *fast* $1^m\ 31^s$ on mean time at Greenwich, August 1st, and on Sept. 4th was *fast* $0^m\ 6^s$ for mean noon at Greenwich.

16. 1887, February 6th, P.M. at ship, latitude 6° 58′ N., observed altitude sun's U.L. 21° 43′ 40″, index correction 0″, eye 18 feet, time by a chronometer $11^h\ 40^m\ 26^s$ (being A.M. at Greenwich), which was *slow* $16^m\ 4^s{\cdot}8$ on mean noon at Greenwich, January 2nd, and on January 20th was *slow* $17^m\ 42^s$ on mean noon at Greenwich.

17. 1887, May 1st, P.M. at ship, latitude 21° 8′ N., observed altitude sun's L.L. 28° 5′ 30″, index correction + 2′ 50″, height of eye 16 feet, time by a chronometer April $30^d\ 18^h\ 50^m\ 29^s{\cdot}4$ (being $6^h\ 50^m\ 29^s{\cdot}4$ A.M. at Greenwich), which was $10^m\ 12^s$ *slow* for mean noon at Greenwich, December 31st, 1886, and on February 17th, 1887, was $7^m\ 33^s{\cdot}6$ *slow* for mean noon at Greenwich.

18. 1887, April 21st, P.M. at ship, latitude at noon 0° 20′ N., observed altitude sun's U.L. 32° 21′ 10″, index correction — 1′ 10″, eye 12 feet, time by a chronometer $3^h\ 44^m\ 1^s$ (being A.M. at Greenwich), which was *slow* $9^m\ 7^s$ for mean noon at Greenwich, November 14th, 1886, and on January 11th, 1887, was *slow* $7^m\ 34^s{\cdot}2$ for mean noon at Greenwich, course since noon S.W. by W. (true), distance 36 miles: required the longitude at the time of observation, and also at noon.

19. 1887, August 21st, A.M. at ship, latitude at noon 0° 20′ S., observed altitude sun's L.L. 33° 49′, index correction + 2′ 10″, eye 15 feet, time by chronometer $8^h\ 14^m\ 0^s$ (being P.M. at Greenwich), which was *slow* $4^m\ 40^s$ for mean noon at Greenwich, March 13th, and on April 30th was *slow* $5^m\ 40^s$ for mean noon at Greenwich, course till noon S.W. by W., distance 36 miles: required longitude at time of sights, and also at noon.

20. 1887, March 20th, A.M. at ship, latitude 0°, observed altitude sun's L.L. 28° 50′ 10″, index correction + 1′, eye 23 feet, time by chronometer $20^d\ 1^h\ 35^m$ (being P.M. at Greenwich), which was $1^m\ 59^s{\cdot}9$ *fast* for mean noon at Greenwich, February 1st, and on February 28th was *fast* $2^m\ 8^s$ for mean noon at Greenwich.

21. 1887, September 23rd, A.M. at ship, latitude 0°, observed altitude sun's L.L. 45° 21′ 10″, index error — 1′ 7″, height of eye 17 feet, time by chronometer September $22^d\ 20^h\ 56^m\ 13^s$, which was *slow* $15^s{\cdot}6$ on Greenwich mean time, April 30th, and on June 1st was *fast* 10^s on Greenwich mean time.

SUMNER'S METHOD.

ON FINDING SHIP'S LINE OF POSITION OR PARALLEL OF EQUAL ALTITUDE.

Problem I.

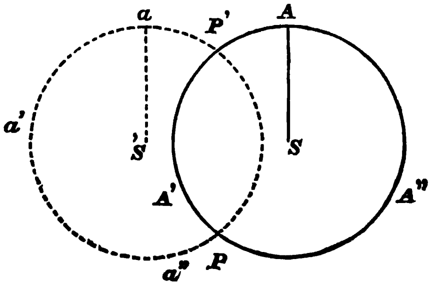
TO FIND THE SHIP'S CURVE OF POSITION OR PARALLEL OF EQUAL ALTITUDE.

177. In the preceding chapters of this work we have treated of methods of finding the position of a point on the earth's surface by the two co-ordinates *latitude* and *longitude;* and, therefore, in all these methods the required position is determined by the intersection of two circles, one a parallel of latitude, and the other a meridian. It is evident that if we could find any two other lines passing through the ship, their intersection would also determine the position of the ship, and thus answer the same purpose as parallels of latitude and meridians. In the following method the position of the ship is determined by circles *oblique* to the parallels of latitude and the meridian. The principle which underlies the method has often been applied, but its value as a practical nautical method was first clearly shown by Capt. T. H. Sumner.

178. Let an altitude of the sun, or any other object, be observed *at any time*, the time being noted by a chronometer regulated to Greenwich time.

Suppose that at this Greenwich time the sun is vertical to an observer at the point S of the globe (Fig. 55), having there an altitude of 90°, and if a small circle A A′A″ be supposed to be described about the point S as a pole, with a distance S A, equal to the zenith distance or complement of the altitude of the sun. It is evident that at all places *within* this circle an observer would, at the given time, observe a smaller zenith distance, and at all places *without* this circle a greater zenith distance; and, therefore, the observation fully determines the observer to be *on* the circumference of the small circle A A′A″. If, then, the seaman can project this small circle upon an artificial globe, or

Fig. 55.



a chart, *the knowledge that he is upon this circle will be just as valuable to him to avoid dangers as the knowledge of either his latitude alone, or his longitude alone*, since one of the latter elements only determines a point to be in a certain circle without fixing upon any particular point of that circle. The small circle of the globe, described from the projection of the celestial object as a pole, we shall call a *circle of position*.

179. A small portion of this circle passing through two positions near together may be considered as a straight line, and this line is evidently perpendicular to the direction of the observed object, and it is this line which has been called the *line of position*.

180. The altitude of another celestial object S′ being taken at the same time (or a second altitude of the same body after a suitable change of bearing) gives a second circle of position (Fig. 55, dotted circle). The observer being on the circumference of each of these circles must be at one of their points of intersection P or P′. In good observations, selected within proper limits, these points, P and P′, lie so far apart that, with a very rough latitude by account, there can be no difficulty in chosing the right one.

181. In finding the longitude by chronometer, an error in the latitude from which the time is computed, affects the resulting longitude in a corresponding degree. If several latitudes, not differing very greatly from the truth, be successively employed in calculating the longitude, each latitude will give a different longitude; and if with each latitude and the longitude deduced from it a point is found on the chart, it will be seen that these points lie very nearly in a straight line,* whose direction is the complement to the bearing of the observed object at the time of observation; in other words, the *line of position* is perpendicular to the direction of the object at the time of observation.

182. Two assumed latitudes, with the resulting longitudes, will be sufficient to determine the *line of position*, provided the latitudes do not greatly differ from the truth. Lay off on the chart these two positions, and join them by a straight line, somewhere on this line, or very near it, the observer's place is to be found; and thus, if this line (being produced) passes through a point of land or other object, the *bearing* of such object is known, though the ship's *place* on the line of its direction is not known.

183. After the observation the ship changes her place, which is usually the case at sea; but, if from any point in the line of position the ship's run be laid off in proper direction according to the ship's course, and through the point thus found a line be drawn parallel to the line of position, the ship's actual place is still somewhere on *this line.*

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* The direction of this line at any point is the direction of the tangent to the curve at this point. The direction of this tangent, as just stated, will be at right-angles to the bearing of the sun at that point. *Hence, by a line of position we may determine the azimuth of the sun.* By reference to the principles of construction of the Mercator's chart, it will be seen that only the loxodromic curve plots as a straight line. The circle of position would plot as an irregular figure, its greatest diameter coinciding with the arc of the meridian. The whole figure could not indeed be plotted on ordinary charts unless the zenith distances M A, M A′, &c., were very small.

It is customary to plot only the small portion of the curve lying between the assumed latitudes, as that is all that is required. For small differences of latitude, as before observed, this would be practically a straight line.

184. If a second observation of the same or any other celestial body be taken, separated from the first by a suitable difference of bearing, and treated in the same manner, another *line of position* may be drawn, which will also pass through the place of observation; and, therefore, the intersection of the two lines will give the ship's place, which may thus be obtained by projection on the chart, without the computation of a double altitude. The intersection is most distinctly marked when the lines cross at right-angles, and they must not in any case cut too acutely or the unavoidable errors of observation will be considerably magnified. The difference of bearings *should not be less than* 45° *nor greater than* 135°.

The foregoing remarks contain the elementary principles of Sumner's Method of finding the ship's position at sea.

185. The latitude, longitude, and time at ship being uncertain, it is required, from an altitude of the sun and the Greenwich time, as found from the chronometer, to project on Mercator's chart a *line of position* or a *parallel of equal altitude*, which shall pass through the position of the ship, and show—

1st—The bearing of the land.

2nd—The sun's true bearing or azimuth.

3rd—The error in the longitude corresponding to any error in the latitude.

186. The method of finding the approximate projection of a circle of position on the Mercator's chart is as follows:—

SOLUTION BY CONSTRUCTION ON MERCATOR'S CHART.*

The Observation.—Take an altitude of the sun and note the corresponding time by chronometer.

RULE LXXV.

1°. **The Calculation.**—*To the time by chronometer apply its original error and accumulated rate, as directed in* Rule LXXI, page 218; the result is the Greenwich date at the instant of observation.

2°. *Take out of the* Nautical Almanac, page II, *the sun's declination and the equation of time for the noon of Greenwich date, and the corresponding hourly difference for each; also, take out the sun's semidiameter.*

3°. *Reduce the sun's declination and equation of time to the Greenwich time, either by multiplying each hourly difference by the* hours and decimals *of an hour in the Greenwich time; or, by multiplying each hourly difference by the hours of*

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* Charts for this problem, price 6d. each, may be had of T. L. Ainsley, South Shields, by Post, 7d.

Greenwich time, and taking aliquot parts of an hour for the minutes of the same: the result *is the* correction *to be* applied *to the sun's declination and equation of time respectively* (Rules LIX and LX, pages 183-186.

4°. *Next find the polar distance* (Rule LXI, page 187).

5°. *Correct the observed altitude for index error* (if any) (±), *dip* (—), *correction in altitude* (—), *and semidiameter* (±), *and thus get the true altitude* (Rule LXIII, page 192).

6°. *Assume two latitudes* differing *about a* degree *or* less, *and embracing the supposed latitude of the ship.*

Note.—It may be convenient to assume two latitudes from 10′ to 30′ on each side of the latitude by account. In the practical application of this problem at sea, it is customary to assume lats. 10′ to 20′ on each side of the supposed one, and determine the corresponding longitudes. In general, assume the latitudes to cover any supposed error in the latitude.

7°. *Find the hour-angle, and thence deduce the longitude* (by the usual method, see longitude by chronometer, Rule LXXIV, pages 224-225), *with each assumed latitude, first from one assumed latitude and then from the other,* as follows:—

(a) *With the altitude, the* less *assumed latitude, and the sun's polar distance.*

(b) *With the altitude, the* greater *assumed latitude, and the sun's polar distance.*

Thus, two longitudes will be found which may be designated A *and* A′ *respectively, and the ship's position may now be conveniently* projected on a chart of large scale. Thus:—

8°. *On the* less *assumed parallel mark off the longitude* A, *and on the* greater *assumed parallel mark off the longitude* A′.

9°. *Join the points* A *and* A′ *by a straight line cutting both parallels, which will be the projection of the* line of position *or* parallel of equal altitudes *passing through the true place of the ship; the direction of this line is found by placing the edge of the parallel rulers on the line* A A′ *and moving them to the centre of the compass, the direction is then seen.*

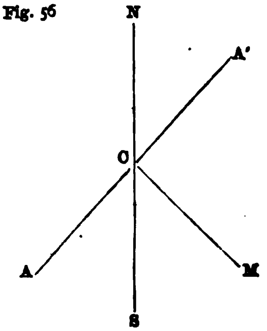
10°. *The* parallel of equal altitude *or* line of position *being produced, if necessary, to meet the coast; the land such a line* passes through *bears from the ship in the same direction as the line lies on the chart.*

To find the Sun's True Azimuth by a Position Line projected on a chart.

11°. *On any point on the line* A A′, *and on that side of the meridian upon which* the sun *is known to be at the time of observation,* i.e., *to the* eastward *if the altitude taken was* A.M., *but to the* westward *if* P.M.; erect a perpendicular, *and it will be in the direction of the sun's true bearing, and the angle it makes with the meridian is the* sun's true azimuth, *which is therefore known on being referred* to the compass on the chart.

Note 1.—Let A A′ (*Fig.* 56) be a line of position on the chart derived from an observed altitude. At any point C of this line erect C M perpendicular to A A′, and let N C S be the meridian passing through C; then S C M is evidently the sun's azimuth. The line C M is, of course, drawn on that side of the meridian M S upon which the sun is known to be at the time of observation. The solution is but approximate, since A A′ should be a curve line, and the azimuth of the normal to it would be different for different points of A A′. It is, however, quite accurate enough for the purpose of determining the error of the compass at sea, which is the only practical application of the problem.

Fig. 56



Note 2.—The difference of longitude between A and A′ will show the error of longitude arising from an error equal to the difference between the assumed latitudes; and hence, by proportion, the error of longitude corresponding to any other error of latitude may be found.

Examples.

Ex. 1. 1887. If at sea on August 28th, P.M. at ship, and uncertain of my position, when the chronometer showed August $28^d\ 3^h\ 22^m\ 0^s$ M.T.G.; suppose the observed altitude of the sun's L.L. to be 35° 47′ 0″, index correction + 1′ 5″, height of eye 16 feet: required the line of bearing when the altitude was taken, assuming the ship to be between latitudes 49° 0′ N. and 50° 0′ N.

It will be observed that in this question the Greenwich date, mean time, is given—in this case August $28^d\ 3^h\ 22^m\ 0^s$; therefore there is no chronometer time to correct for error and rate, but from the Nautical Almanac, page II, the Decl. and Eq. T. is taken and corrected in the usual way.

Greenwich date		August $28^d\ 3^h 22^m$	Obs. alt. sun's L.L.	35° 47′ 0″
			Index corr.	+ 1 5
		or $3^h{\cdot}37$*		35 48 5
	$6{,}0)22^m{\cdot}0$*		Dip	− 3 50
	$3^h{\cdot}37$			35 44 15
			Corr. of alt.	− 1 12
				35 43 3
			Semidiameter	+ 15 53
			True alt.	35 58 56

	Decl., page II, N.A.	Var. 1^h.	Eq. T., page II, N.A.		H.D.
August 28th, noon	9° 44′ 45″ N. *decr.*	52″·97	$1^m 8^s{\cdot}92$ *decr.*		0·728
Corr. for $3^h\ 22^m$	− 2 59	3·37	2·45		3·37
Red. decl.	9 41 46	37079	Red. Eq. T. 1 6·47		·5096
		15891	(To be *added* to A.T.)		2184
Polar dist.	80 18 14	15891			2184
		6,0)17,8·5089		Corr.	2·45336
		2 58·5			

It will be further noticed that at the end of the question two assumed latitudes are given—in this case 49° 0′ N. and 50° N. *For each lat.*, with the true alt. and pol. dist. (as above) next proceed in the usual way to find the longitudes.

True alt.	35° 58′ 56″			Altitude	35° 58′ 56″		
Latitude	49 0 0	sec.	0·183057	Latitude	50 0 0	sec.	0·191933
Polar dist.	80 18 14	cosec.	0·006249	Polar dist.	80 18 14	cosec.	0·006249
	165 17 10				166 17 10		
	82 38 35	cos.	9·107381		83 8 35	cos.	9·076971
	46 39 39	sine	9·861716		47 9 39	sine	9·865262
A.T.S. Aug. 28^d	2^{h}58^{m}25^s	log.	9·158403	A.T.S. Aug. 28^d	2^{h}54^{m}34^s	log.	9·140415
Eq. time	+ 1 6			Eq. time	+ 1 6		08
M.T.S. Aug. 28^d	2 59 31			M.T.S. Aug. 28^d	2 55 40		33
M.T.G. Aug. 28^d	3 22 0			M.T.G. Aug. 28^d	3 22 0		
Long. in time	0 22 29			Long. in time	0 26 20		
Longitude (A)	5° 37′ 15″ W.			Longitude (A′)	6° 35′ 0″ W.		

Thus, then, has been obtained two positions, viz.:—

A. In lat. 49° 0′ N., long. 5° 37′ 15″ W.
A′. In lat. 50° 0′ N., long. 6° 35′ 0″ W.

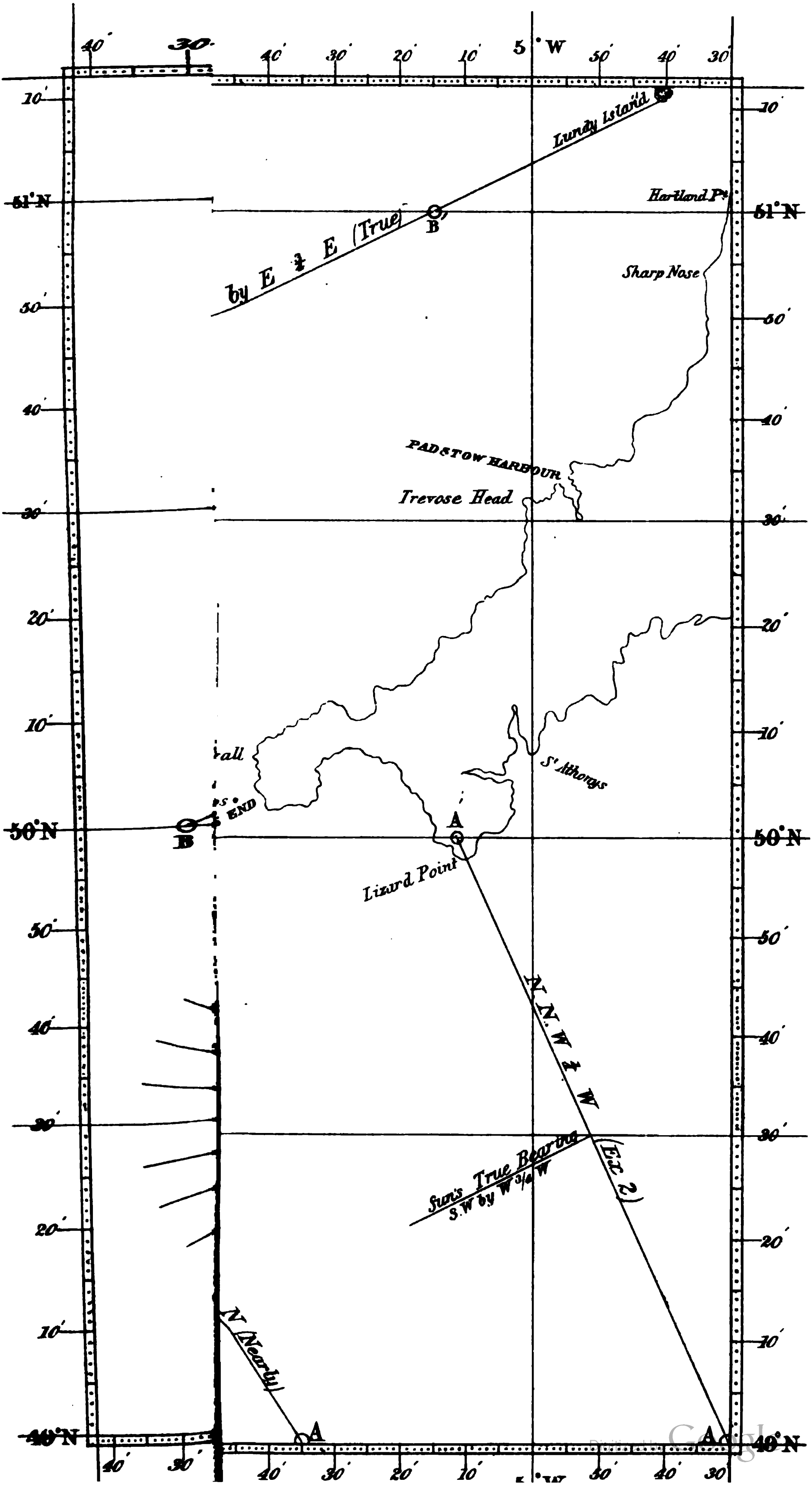
NOTE.—The results obtained by working out this question are laid down in the accompanying chart, and should be carefully studied by the candidate.

On a Mercator's chart mark the point A in latitude 49° N., and longitude 5° 37¼′ W. (exactly as a ship's position is pricked off on the chart by the aid of dividers and parallel rules); also mark the point A′ in latitude 50° N. and longitude 6° 35′ W. Join A and A′ by a straight line, and the ship will be on this line, it being the projection of *the line of position of the ship*, or as sometimes called, the *parallel of equal altitude of the ship*. The line will be found to pass through the Bishop Rock, and when referred to the compass on the chart, the light will be found to bear N.W. by N. ½ N. Consequently, although the *exact* position of the ship is not known, it is certain that by steering a true N.W. by N. ½ N. course the ship will make the Bishop Rock. (See Ex. 1, plate.)

To find the Sun's True Azimuth.—From any point on A A′ draw a perpendicular to A A′, and this will give the true bearing of the sun, which will be found to be S.W. by W. ½ W. If this line be produced it will give the perpendicular on the other side of A A′, bearing N.E. by E. ½ E.; the former, however, lying in the direction of the sun, and as the observation is made in the afternoon, gives the sun's true azimuth.

NOTE 1.—The above calculations should be carried on together, that is, the formula for each should be prepared, and the logarithms, &c., filled in, taking care to take out of the tables, at the same time, those logarithms which are found at the same opening of the tables. Thus, after taking out log. secant of lat. 49° take log. secant of lat. 50°; log. cosecant of polar distance is the same in both instances; cosine of 82° 38′ 35″ is then taken out, and at the same time cosine of 83° 8′ 35″; the sine of 46° 39′ 39″ and sine of 47° 9′ 39″ may be taken out at the same time, and, lastly, the hour-angle in both cases is taken out at the same time. Consequently, the two calculations required the tables to be opened only five times, the same as if there were only one calculation to be performed. The observation here made is, of course, applicable to all the following examples.

NOTE 2.—The longitude of A and A′ being 5° 37¼′ and 6° 35′ W., the difference is 58′, and the difference of their latitudes is 1° = 60′. Hence, an error of 60′ in latitude gives an error of 58′ in longitude; and, if we state 60′ : 10′ :: 58′ : 10′ (nearly), we find that an error of 10′ in latitude gives an error of 10′ in longitude. That is, if we compute the longitude by chronometer from the altitude of the sun, in this example, and assume a latitude which is 10′ in error, the longitude thus found will be 10′ (nearly) in error.


40'
30'
40'
30'
20'
10'
5° W
50'
40'
30'
10'
51°N
50'
40'
30'
20'
10'
50°N
50'
40'
30'
20'
10'
49°N
Lundy Island
by E ¼ E (True)
B
Hartland Pt
Sharp Nose
PADSTOW HARBOUR
Trevose Head
all
s' END
B
A
St Anthonys
Lizard Point
N.N.W ¼ W
(Ex. 2)
Sun's True Bearing
S.W by W 3/4 W
N (Nearly)
A
A

Ex. 2. 1887. April 24th, A.M. at ship, lat. D.R. 49° 40′ N., long. D.R. 5° 20′ W. The obs. alt. sun's L.L. was 30° 22′ 40″, index corr. — 1′ 17″, height of eye 18 feet, when a chronometer showed April 23rd $20^h\ 29^m\ 27^s$, mean time at Greenwich.

Required to project on the chart a line of position, and also a line of sun's bearing.

Green. date	April 23^d	$20^h 29^m 27^s$
		24
Time from noon	April 24^d	3 31
		$3^h·5$

Decl., page II, N.A.		H.D.	Eq. T., page II, N.A.		H.D.
April 24^d, noon	12° 50′ 56″ N. *incr.*	49″·43	April 24^d, noon	$1^m 54^s·4$	0·460
Corr. for $3^h·5$	— 2 53	3·5	Corr. for $3^h·5$	— 1·6	3·5
Red. decl.	12 48 3 N.	24715	Red. Eq. time	1 52·8	2300
	90	14829	(To be *subt.* from A.T.)		1380
Polar dist.	77 11 57	6,0)17,3·005			1·6100
		2 53·0			

To find point A, latitude 49° 30′ N.

Obs. alt. sun's L.L.	30° 22′ 40″	Altitude	30° 31′ 45″		
Index corr.	— 1 17	Latitude	49 30 0	sec.	0·187456
		Polar dist.	77 11 57	cosec.	0·010931
	30 21 23				
Dip	— 4 4		157 13 42		
	30 17 19		78 36 51	cos.	9·295380
Corr.	— 1 30				
			48 5 6	sine	9·871652
	30 15 49				
Semidiameter	+ 15 56	Hour-angle	$3^h 50^m 20^s$	log.	9·365419
			24		42
True altitude	30 31 45				
		App. T. ship, April 23^d	20 9 40		2
		Eq. time	— 1 53		
		M.T. ship, April 23^d	20 7 47		
		M.T. Green., April 23^d	20 29 27		
		Longitude in time	0 21 40 = 5° 25′ W. (A)		

To find point A′ in latitude 49° 50′ N.

Altitude	30° 31′ 45″		
Latitude	49 50 0	sec.	0·190431
Polar dist.	77 11 57	cosec.	0·010931
	157 33 42		
	78 46 51	cos.	9·289059
	48 15 6	sine	9·872783
Hour-angle	$3^h 49^m 41^s$	log.	9·363204
	24		12
App. T. ship, April 23^d	20 10 19		8
Eq. time	— 1 53		
M.T. ship, April 23^d	20 8 26		
M.T. Green., April 23^d	20 29 27		
Longitude in time	0 21 1 = 5° 15¼′ W. (A′)		

Space for minor corrections.

cosec.	
77° 11′ 0″ =	0·010958
Pts. for 57 =	— 27
77 11 57	0·010931
Tab. diff. =	48
	57
	336
	240
Corr. =	27,36

cosine.	
78° 36′ 0″ =	9·295913
Pts. for 51 =	— 533
78 36 51	9·295380
Tab. diff.	1045
	51
	1045
	5225
Corr. =	532,95

sine	
48° 5′ 0″ =	9·871641
Pts. for 6 =	+ 11
48 5 6	9·871652
Tab. diff.	189
	6
Corr. =	11,34

cosine.	
78° 46′ 0″ =	9·289600
Pts. for 51 =	— 541
78 46 51	9·289059
Tab. diff.	1061
	51
	1061
	5305
Corr. =	541,11

sine.	
48° 15′ 0″ =	9·872772
Pts. for 6 =	+ 11
48 15 6	9·872783
Tab. diff.	188
	6
Corr. =	11,28

On Mercator's chart mark the point A in latitude 49° 30′ N., long. 5° 25′ W.; also, mark the point A′ in latitude 49° 50′ N., long. 5° 15½′ W. Join A and A′ by a straight line and the ship will be on this line *somewhere*, it being the projection of the *line of position of the ship*, or as it is also sometimes called, the *parallel of equal altitude of the ship*. The line A A′ being produced until it meets the land it will be found to intersect the land near the Lizard Point; and when referred to the compass on the chart it will be found to bear N. by E. ½ E. (true). Consequently, although the *exact* position of the ship is not known, it is certain that by steering N. by E. ½ E. the ship will make the Lizard.

For the Sun's True Azimuth.—From any point on A A′ draw a line at right-angles, or eight points from the Northerly direction of the Line of Position to the Eastward (the sight was taken A.M.), and the sun's bearing will be found to be E. by S. ½ S.

Problem II.

SUMNER'S METHOD OF FINDING LATITUDE AND LONGITUDE. (FOR ONLY MATES, FIRST MATES, AND MASTERS.)

187. To find the latitude and longitude of a ship by circles of position projected on Mercator's chart.

Having given two altitudes of the sun, the times of observation by chronometer (whose error for Greenwich mean time is known), also the sun's declination at both times, and the latitude by dead reckoning, to find the true latitude and longitude of the ship.

RULE LXXVI.

1°. *Find the Greenwich date of each observation by correcting the times shown by chronometer for error and accumulated rate.*

2°. *Find the declination and polar distance for each of the Greenwich dates.*

3°. *Find the* equation of time *corresponding to each Greenwich date.*

4°. *Correct each observed altitude for index error* (if any) (±), *dip* (—), *refraction* (—), *parallax* (+), *and semidiameter* (±).

5°. *Assume two latitudes,* differing *about a degree or less, and embracing the supposed latitude of the ship; thus it may be convenient to assume the lattitudes from* 10′ to 30′ *on each side of the supposed latitude of the ship.*[*]

NOTE.—It is scarcely necessary to warn the intelligent navigator against making an assumption of latitude that shall render the computation of the hour-angle impossible: the sum of the altitude, latitude, and polar distance can never exceed 180°.

6°. *Compute the longitude* (by the usual method) *with each assumed latitude, first from one altitude and then with the other*, as follows:—

(a) *With the 1st altitude, the* less *assumed latitude, and the sun's polar distance, corresponding to the time of the first observation:* call this A.

---

[*] It is not, however, essential that the same assumed latitudes should be used in computing both lines of position; it is only more convenient to do so, as it saves some logarithms. In the case of two altitudes of the same object, as of the sun in this case, where a course and distance have been made in the interval, if the course has been nearly North or South, it would be better to assume two latitudes differing from those used for the first observation, and such that they may be more in accordance with the altered position of the ship.

(b) *With the 1st altitude, the* greater *assumed latitude, and the sun's polar distance, corresponding to the first observation:* call this A′.

(c) *With the 2nd altitude, the* less *assumed latitude, and the sun's polar distance, at the time of taking the second observation:* call this B.

(d) *With the 2nd altitude, the* greater *assumed latitude, and the sun's polar distance, corresponding to the time of the second observation:* call this B′.

Thus, four longitudes will be found which may be designated as A, A′, B, and B′ respectively, to facilitate reference to them.

7°. *On Mercator's chart project* A A′, *the* ship's line of position, *or* parallel of equal altitude, *corresponding to the first altitude.* Thus,

(a) *On the* less *assumed parallel of latitude mark the longitude* A, *and in the* greater *assumed parallel of latitude mark the longitude* A′.

(b) *Join the points* A *and* A′ *by a straight line, which will be the projection of the* ship's line of position *at the first observation,* and on or near this or this produced the ship is situated. *To find the* direction *place the edge of the parallel rulers on the line* A A′ *and move them to the centre of the compass, the direction is then seen.*

8°. *Project, in exactly the same manner,* B B′, *the* ship's line of position, *corresponding to the second altitude.* That is,

(a) *On the* less *assumed latitude mark the spot corresponding to longitude* B, *and on the* greater *assumed latitude mark the corresponding longitude* B′.

(b) *And the line joining the points* B B′, *will be a second* ship's line of position, *and* on *or* near *this or this produced the ship is also situated.*

The position of the ship *is at the* intersection *of the* two lines *thus produced,** *from which its* Latitude *and* Longitude *are found in the usual way on the graduated meridian and the graduated parallel.*

Or proceed thus:—

9°. *On the* less *assumed latitude mark the* longitudes A *and* B; *on the* greater *assumed latitude mark the* longitudes A′ *and* B′; *draw a line through the* points A *and* A′, *cutting both parallels; also draw another line through the* points B *and* B′: *the position of the ship is at the* intersection *of these lines.*

The following example will illustrate the last paragraph of the rule:—

Ex. On the 1st day of August, 1887, at about 10^h apparent time at ship, an altitude of the sun was observed, the latitude by dead reckoning being 50° 16′ North. The longitude as ascertained by working with the assumed latitudes 50° N. and 51° N. are as follows:—

Longitude corresponding to 50° N. is 7° 5′ W. (A).
" " 51° N. is 8° 15′ W. (A′).

Proceed as in the preceding rule to project the ship's line of position.

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* If the lines of position when computed and projected intersect considerably beyond one or other of the assumptions, then take another latitude, a little beyond that of the intersecting point, compute anew for this, and so project again. The position will be more accurately determined in this manner.

Mark on the chart the spot (A) corresponding to latitude 50° N. and longitude 7° 5′ W. (see plate). Again, mark the spot corresponding to latitude 51° N. and longitude 8° 15′ W. on the chart (A′). Draw a line connecting these two spots, A A′.

At 3^h P.M. of the same day an altitude of the sun was observed, the ship having remained stationary between the observations, working with the same assumed latitudes.

Longitude corresponding to 50° N. is 8° 30′ W. (B).
" " 51° N. is 5° 15′ W. (B′).

Project, in exactly the same manner as above, the ship's line of position corresponding to the second altitude by marking off on the parallel of 50° N., the longitude of B = 8° 30′ W., and the longitude B B′ = 5° 15′ W. on the parallel of 51° N. Connect the two points B and B′ by a straight line.

Then A A′ in the diagram (see plate) shows the two longitudes corresponding to the *first observation*, and B B′, the longitudes corresponding to the *second observation.*

The intersection of these lines at C shows the position of the ship.

The latitude is 50° 19′ N. instead of 50° 16′ N., as by dead reckoning; the longitude is 7° 27½′ W.

The line B B′, prolonged until it meets the land, gives the bearing of Lundy Island N.E. by E. ¾ E. (true).

10°. **If the ship has changed her station between the observations.**—*Set off from any part of the line* A A′ *the* distance *sailed between the observations in the direction of the true course made good. Through the point thus found draw a parallel to* A A′, *and produce it till it meets* B B′; *and the* intersection *of its* new position *will give the* place of the ship *at the* second observation.

NOTE.—When the ship is steering a straight course, the line indicating the track can, from any point in A A′, be drawn, and the distance laid off, on the completion of the second observation. This evidently accomplishes the same result as correcting the altitudes. It possesses the advantage of being simple, and when the chart has the magnetic compass *plotted* upon it, the compass course can be laid off between the observations. Should the run happen to be the *same* or the *opposite* point to the first line of position, then where the two lines of position, *i.e.*, the first and second, cross each other, will show the ship's position; consequently, it will not be necessary to lay off the run in such a case.

The following examples will illustrate this part of the rule:—

EXAMPLES.

EX. 1. Suppose in the forenoon (see preceding example) an altitude of the sun was observed, the latitude by dead reckoning being 50° 14′ N. The longitudes, as ascertained by working with the assumed latitudes 50° N. and 51° N., are as follows:—

Longitude corresponding to 50° N. is 7° 5′ W. (A).
" " 51° N. is 5° 15′ W. (A′).

In the afternoon of the same day a second altitude of the sun was observed, the ship in the interval having sailed N.E. (true) 20 miles. Working with the same assumed latitudes as before, the

Longitude corresponding to 50° N. is 8° 30′ W. (B).
" " 51° N. is 5° 15′ W. (B′).

Project A A′, the ship's line of position, or line of equal altitudes, corresponding to the *first* altitude. The ship having moved in the interval, the projection of the first line of equal altitudes, must now be moved parallel to itself in the direction of and through the distance of the run. Set off from any part of the line A A′, 20 miles due N.E. Draw through this point a line *a a′* parallel to A A′, this will be the line of equal altitude at the time of the first observation, corrected for change of station. (See plate.) Next project B B′, the line of equal altitude corresponding to the second observation. The intersection at C′ of the line B B′ with *a a′* or that corresponding to the first observation as corrected for change of station, shows the position of the ship. The latitude is 50° 28′ N., instead of 50° 14′ N., as by dead reckoning; the longitude is 6° 58′ W.

It will be evident that the second observation will not give the same altitude as if the ship had remained stationary, but will give a line of position or line of equal altitude 20 geographical miles further to N.E. Be careful not to confound these with longitudinal miles, as in this lat. 20 geographical miles equal 31 miles of longitude.

Ex. 2. It is required to project two observations of the sun, showing by the intersection of their lines of position the place of the ship, supposing the ship to have sailed N.E. by E. ½ E. (true), 19 miles, in the interval between the observations.

The longitudes at the first observation, by working with the assumed latitudes 49° 40′ N. and 50° 0′ N., were as follows:—

Longitude corresponding to latitude 49° 40′ N. is 177° 56¾′ E. (A).
" " " 50° 0′ N. is 179° 27¼′ W. (A′).

Working with the same assumed latitudes, the corresponding longitudes at the second observation were as follows:—

Longitude corresponding to lat. 49° 40′ N. is 179° 48⅓′ W. (B).
" " " 50° 0′ N. is 179° 48′ W. (B′).

Mark on the chart the spot corresponding to A, lat. 49° 40′ N., long. 177° 56¾′ E.; also the point A′, lat. 50° 0′ N., long. 179° 27¼′ W. Connect these two points by a straight line; this is the ship's line of position at the first observation. Set off from the line A A′ 19 miles in the direction of the course, N.E. by E. ½ E. (true), and draw a line *a a′* through this point parallel to A A′, which will be a projection of the line of position at the first observation for the run of the ship.

Again, mark the spot B in lat. 49° 40′ N., long. 179° 48⅓′ W., and the spot B′ in lat. 50° 0′ N., long. 179° 48′ W.; these two points being joined by a straight line are a projection of the ship's line of position at the second observation, and the intersection of this line B B′ with the line *a a′* (or the line of position at the first observation corrected for change of station) gives the place of the ship at the second observation, lat. C′ 50° 3′ N., long. 179° 48′ W.

To find the Line of Position and Sun's True Bearing at first observation.

The first line of position, A A′, trends E. by N. and W. by S., and by drawing a line at right-angles, or eight points from the northerly direction of the line of position to the eastward (the altitude being taken A.M.) we have the sun's true bearing is S. by E. or S. 11¼° E.

We shall now proceed to work out in full detail an example showing how to determine the ship's position by the intersection of lines of position corresponding to two altitudes of the sun, having given the ship's course and distance in the interval.

Ex. 3. 1887, March 1st, A.M. at ship, and uncertain of my position, when the chron. showed February $28^{d}\ 23^{h}\ 14^{m}\ 15^{s}$ M.T.G.; suppose the obs. alt. sun's L.L. 29° 46′ 50″, and again P.M. same day, when the chronometer showed March $1^{d}\ 4^{h}\ 14^{m}\ 55^{s}$, the obs. alt. sun's L.L. 15° 47′ 10″, the ship having made 20 miles on a true N.E. course, height of eye 20 feet: required the line of position, also the bearing of the sun when the first altitude was taken, and the position of the ship by Sumner's Method when the second altitude was taken.

First Observation.

Green. date, Feb. 28d 23h 14m 15s

Time from noon, Mar. 1d 0 45 45

0h·76

Decl., page II, N.A.		H.D.	Eq. T., page II, N.A.		H.D.
Mar. 1d, noon	7° 35′ 22″ S. *decr.*	56″·97	Mar. 1d	12m 33s·5 *decr.*	0s·493
Corr. for 0h·73	+ 0 43	0·76	Corr. for 0h·7	+ 0·4	·8
Red. decl.	7 36 5 S.	34182 39879	Red. Eq. T.	12 33·9	0s·3944
Polar dist.	97 36 5	43·2972	(To be *added* to A.T.)		

Correction of observed altitude.

Obs. alt. ☉'s L.L.	29° 46′ 50″
Dip	— 4 17
	29 42 33
Corr.	— 1 32
	29 41 1
Semidiameter	+ 16 10
True alt.	29 57 11

Computation of time and longitude, with assumed latitude 49° N.

Altitude	29° 57′ 11″		
Latitude	49 0 0	sec.	0·183057
Polar dist.	97 36 5	cosec.	0·003833
	176 33 16		
	88 16 38	cos.	8·478041
	58 19 27	sine	9·929946
Hour-angle	1h 31m 32s	log.	8·594877 64 — 24
App. T. ship, Feb. 28d	22 28 28		
Eq. time	+ 12 34	gives 3s	
M.T. ship, Feb. 28d	22 41 2		
M.T. Green., Feb. 28d	23 14 15		
Longitude in time	33 13		
Long. A	8° 18¼′ W.		

With assumed latitude 50° N.

Altitude	29° 57′ 11″		
Latitude	50 0 0	sec.	0·191933
Polar dist.	97 36 5	cosec.	0·003833
	177 33 16		
	88 46 38	cos.	8·329191
	58 49 27	sine	9·932262
Hour-angle	1h 17m 58s	log.	8·457219 665 — 57 = 3s
App. T. ship, Feb. 28d	22 42 2		
Eq. time	+ 12 34		
M.T. ship, Feb. 28d	22 54 36		
M.T. Green., Feb. 28d	23 14 15		
Longitude in time	19 39		
Long. A′	4° 54¾′ W.		

Space for minor corrections.

cosec.
97° 36′ 0″ = 0·003832
Pts. for 5 = + 1
97 36 5 0·003833
Tab. diff. = 28
5
Corr. = 1,40

cosine.
88° 16′ 30″ = 8·478601
Pts. for 8 = — 560
88 16 38 = 8·478041
Tab. diff. 700
8
560,0

NOTE.—The half sum being greater than 88°, it must be taken out at the beginning of Table XXV, remembering that here the Tab. diffs. are given for 10″, and only *one* figure must be cut off to the right.

sine.
58° 19′ 0″ = 9·929911
Pts. for 27 = + 35
58 19 27 9·929946
Tab. diff. 130
27
910
260
Corr. 35,10

cosine.
88° 46′ 30″ = 8·329980
Pts. for 8 = — 789
88 46 38 8·329191
Tab. diff. 986
8
788,8

sine.
58° 49′ 0″ = 9·932228
Pts. for 27 = + 34
88 49 27 = 9·932262
Tab. diff. 127
27
889
254
Corr. = 34,29

Space for minor corrections.

cosec.
97°31′ 0″ = 0·003748
Pts. for 20 = + 6
97 31 20 = 0·003754
Tab. diff. = 28
20
5,60

cosine.
81°13′ 0″ = 9·183834
Pts. for 35 = − 477
81 13 35 = 9·183357
Tab. diff. 1364
35
6820
4092
477,40

sine.
65°17′ 0″ = 9·958271
Pts. for 44 = + 43
65 17 44 = 9·958314
Tab. diff. 97
44
388
388
42,68

cosine.
81°43′ 0″ = 9·158569
Pts. for 35 = − 507
81 43 35 = 9·158062
Tab. diff. 1448
35
7240
4344
506,80

sine.
65°47′ 0″ = 9·959995
Pts. for 44 = + 42
65 47 44 = 9·960037
Tab. diff. 95
44
380
380
41,80

Second Observation.

Green. date, March 1st, $4^h\ 14^m\ 55^s$.

	Decl., page II, N.A.	H.D.		Eq. T., page II, N.A.	H.D.
Mar. 1^d, noon	7°35′ 22″ S. *decr.*	56″·97	Mar. 1^d	$12^m 33^s·5$ *decr.*	0·493
Corr. for $4\frac{1}{4}^h$	— 4 2	$4\frac{1}{4}$	Corr. for $4\frac{1}{4}^h$	— 2·1	$4\frac{1}{4}$
Red. decl.	7 31 20 S.	22788	Red. Eq. T.	12 31·4	1972
		1424	(To be *added* to A.T.)		123
Polar dist.	97 31 20	6,0)24,2·12			2·095
		4 2·1			

Correction of observed altitude.

Obs. alt. ⊙'s L.L.	15°47′ 10″
Dip	— 4 17
	15 42 53
Corr.	— 3 12
	15 39 41
Semidiameter	+ 16 10
True alt.	15 55 51

Computation of time and longitude, with assumed latitude 49° N.

Altitude	15°55′ 51″		
Latitude	49 0 0	sec.	0·183057
Polar dist.	97 31 20	cosec.	0·003754
	162 27 11		
	81 13 35	cos.	9·183357
	65 17 44	sine	9·958314
App. T. ship, March 1^d	$3^h 39^m 55^s$	log.	9·328482
Eq. time	+ 12 31		
M.T. ship, March 1^d	3 52 26		
M.T. Green., March 1^d	4 14 55		
Longitude in time	0 22 29		
Long. B	5°37′ 15″ W.		

With assumed latitude 50° N.

Altitude	15°55′ 51″		
Latitude	50 0 0	sec.	0·191933
Polar dist.	97 31 20	cosec.	0·003754
	163 27 11		
	81 43 35	cos.	9·158062
	65 47 44	sine	9·960037
App. T. ship, March 1^d	$3^h 35^m 55^s$	log.	9·313786
Eq. time	+ 12 31		
M.T. ship, March 1^d	3 48 26		
M.T. Green., March 1^d	4 14 55		
Longitude in time	0 26 29		
Long. B′	6°37′ 15″ W.		

Project A A′, the ship's line of position, or line of equal altitudes, corresponding to the *first* altitude. Next project B B′, the line of equal altitudes corresponding to the second observation. The ship having moved in the interval between the observations, the projection of the first line of equal altitudes, must now be moved parallel to itself in the direction of and through the distance of the run. Set off from any part of A A′, 20 miles due N.E., as follows:—

From the graduated meridian opposite the line extending from A to A′ take off the distance 20 miles with the dividers; lay the dividers down, and taking the parallel rules place them on the compass in the corner of the chart, over N.E. and S.W.; then work the parallels (strictly preserving the direction) towards the line of the first position A to A′; having reached that line, draw another extending from any part of it in the direction of the course N.E., and on this last line lay off the 20 miles of distance already taken with your dividers. Lay the edge of the parallels on the line A A′, and working them (preserving the direction) to the point just laid off; draw through this point another line *a a′* parallel to A A′. The intersection at C′ of the line B B′ with *a a′* or that of the first observation as corrected for change of station, shows the position of the ship. The latitude is 49° 42′ N., the longitude is 6° 20′ W.; line of bearing at first observation E.N.E. (N'ly), W.S.W. (S'ly). True azimuth S. 24° E.

NOTE.—The longitudes corresponding to the two latitudes by the second observation are not now furnished to the Candidate by the Examiner; the Candidate will, consequently, be required to work out the whole of the problem for themselves, in place of the explanation formerly required, and must be prepared to find the sun's bearing at the time of taking either the first or second observation.

EXAMPLES FOR PRACTICE.

1. 1887. If at sea, March 1st, A.M. at ship, and uncertain of my position, when the chronometer showed February $28^d\ 10^h\ 50^m\ 54^s$ M.T.G.; suppose the obs. alt. sun's L.L. 29° 46′ 50″: and again P.M. on the same day, when the chronometer showed February $28^d\ 15^h\ 50^m\ 49^s$ M.T.G., obs. alt. sun's L.L. 15° 47′ 10″, the ship having made 32 miles on a true E. by N. course, height of eye 19 feet.

Required the line of bearing when the first altitude was taken, and also the bearing of the sun by projection, and the position of the ship by Sumner's Method when the second altitude was taken, assuming the ship to be between latitudes 49° 10′ N. and 49° 40′ N.

2. 1887, May 19th, A.M. at ship, and uncertain of my position, when the chronometer showed May $18^d\ 22^h\ 1^m\ 39^s$ M.T.G., obs. alt. sun's L.L. 48° 57′, and again, P.M. the same day, when the chronometer showed May $19^d\ 3^h\ 41^m\ 18^s$ M.T.G., obs. alt. sun's L.L. 40° 45′ 15″, the ship having made between the observations 25 miles on a true E.N.E. course, height of eye 18 feet: required the line of bearing when the first altitude was taken, and the position of the ship by Sumner's Method when the second altitude was observed, assuming latitudes 48° 30′ N. and 49° 0′ N.

3. 1887. If at sea, November 8th, A.M. at ship, and uncertain of my position, when the chronometer showed November $7^d\ 22^h\ 29^m\ 2^s$; suppose obs. alt. sun's L.L. 19° 49′; and again, P.M. on the same day, when the chronometer showed November $8^d\ 3^h\ 48^m\ 57^s$ M.T.G., obs. alt. sun's L.L. 10° 50′ 30″, the ship having made 41 miles on a true N.E. by E. ¼ E. course in the interval, height of eye 19 feet: required the line of bearing when the first altitude was taken, assuming the ship to be between lats. 48° 10′ N. and 48° 40′ N.

4. 1887, February 3rd, A.M. at ship, and uncertain of my position, when the chronometer showed February $2^d\ 22^h\ 17^m\ 16^s$ M.T.G., obs. alt. sun's L.L. 19° 49′ 50″; and again, P.M. same day, when the chronometer showed February $3^d\ 3^h\ 37^m\ 11^s$ M.T.G., obs. alt. sun's L.L. 10° 53′ 30″, the ship having made 39 miles on a true E. by N. ½ N. course in the interval, height of eye 19 feet: required the line of bearing when the first altitude was taken, and the position of the ship by Sumner's Method when the second altitude was observed, assuming the ship to be between lats. 48° 10′ N. and 48° 40′ N.

5. 1887, April 1st, A.M. at ship, and uncertain of my position, when the chronometer showed March $31^d\ 20^h\ 45^m\ 0^s$ M.T.G., obs. alt. sun's L.L. 27° 47′ 10″; and again, P.M. same day, when the chronometer showed April $1^d\ 1^h\ 58^m\ 40^s$ M.T.G., obs. alt. sun's L.L. 37° 36′ 10″, the ship having sailed 16½ miles on a (true) N.W. ½ W. course in the interval between the observations, height of eye 20 feet, required the line of bearing when the first altitude was taken, and the position of the ship by Sumner's Method when the second altitude was taken, assuming the ship to be between latitudes 51° 0′ N. and 51° 30′ N.

6. 1887, March 27th, A.M. at ship, and uncertain of my position, when chronometer showed March $26^d\ 10^h\ 26^m\ 24^s$ G.M.T., obs. alt. sun's L.L. 36° 38′ 30″; again, P.M. same day, when chronometer showed March $26^d\ 16^h\ 37^m\ 10^s$, obs. alt. sun's L.L. 15° 15′ 20″, height of eye 22 feet, course and distance sailed in the interval between the observations S. by E. ¾ E. (true), distance 24 miles: required the line of position, also the bearing of the sun by projection when the first altitude was taken, and the position of the ship when the second altitude was observed, assuming the ship to be between latitudes 51° 40′ N. and 51° 10′ N.

7. 1887, June 11th, A.M. at ship, and uncertain of my position, when the chronometer showed June $10^d\ 16^h\ 54^m\ 10^s$ M.T.G., the obs. alt. sun's L.L. 31° 9′ 20″; and again, A.M. same day, when the chronometer showed June $10^d\ 19^h\ 10^m\ 36^s$ M.T.G., obs. alt. sun's L.L. 52° 50′ 15″, the ship having made 15 miles on a true N.N.W. course in the interval, height of eye 15 feet: required the line of position, also the true bearing of the sun by projection when the first altitude was taken, and the latitude and longitude of the ship when the second altitude was observed, assuming latitudes 48° 0′ N. and 48° 20′ N.

8. 1887, January 24th, A.M. at ship, being uncertain of my position, when the chronometer showed January $24^d\ 9^h\ 14^m\ 44^s$, obs. alt. sun's L.L. 9° 40′ 10″; and again, P.M. same day, when the chronometer showed January $24^d\ 13^h\ 14^m\ 30^s$ M.T.G., obs. alt. sun's L.L. 18° 31′ 15″, the ship having made 23 miles on a true S.E. ¼ S. course in the interval, height of eye 22 feet: required the line of position when the second altitude was taken; also the bearing of the sun by projection, and the latitude and longitude of the ship when the second altitude was taken, the ship being supposed to be between the parallels of 51° 15′ N. and 50° 45′ N.

9. 1887, March 21st, A.M. at ship, being uncertain of my position, when the chronometer showed March $20^d\ 20^h\ 38^m\ 58^s$, obs. alt. sun's L.L. 22° 49′ 50″; again, P.M. same day, when chronometer showed March $21^d\ 2^h\ 18^m\ 50^s$ M.T.G., obs. alt. sun's L.L. 32° 29′ 50″, the ship having made 29 miles on a true N. 52° W. course in the interval, height of eye 21 feet: required the line of position when the first altitude was taken, also the sun's true bearing by projection, and the latitude and longitude of the ship when the second altitude was observed, assuming the ship to be between the latitudes 50° 10′ N. and 50° 50′ N.

10. 1887, December 30th, A.M. at ship, being uncertain of my position, when chronometer showed December $29^d\ 21^h\ 36^m\ 8^s$ M.T.G., obs. alt. sun's U.L. 10° 8′ 10″; and again, P.M. same day, when the chronometer showed December $30^d\ 0^h\ 51^m\ 54^s$ M.T.G., obs. alt. sun's U.L. 16° 15′ 20″, the ship sailed E.N.E. 29½ miles in the interval, height of eye 22 feet: required the line of position, also the true bearing of the sun by projection when the first altitude was taken, and the position of the ship by Sumner's Method when second altitude was observed, assuming the ship to be between lats. 50° 0′ N. and 50° 20′ N.

11. 1887, June 17th, A.M. at ship, and uncertain of my position, when chronometer showed June $16^d\ 18^h\ 24^m\ 3^s$, obs. alt. sun's L.L. 51° 50′ 40″; again, P.M. same day, when chronometer showed June $16^d\ 21^h\ 23^m\ 30^s$, obs. alt. sun's L.L. 63° 34′ 1″, the ship having made 33 miles on a true S.E. ½ S. course, height of eye 20 feet: required the line of position, also the bearing of the sun by projection when the first altitude was taken, and the latitude and longitude when the second altitude was observed, assuming latitudes 48° 50′ N. and 48° 10′ N.

12. 1887, October 29th, A.M. at ship, and uncertain of my position when a chronometer showed October $29^d\ 4^h\ 9^m\ 12^s$ G.M.T., obs. alt. sun's L.L. 28° 18′; again, P.M. same day, when chronometer showed Oct. $29^d\ 7^h\ 39^m\ 12^s$, obs. alt. sun's L.L. 16° 40′, the ship having sailed in the interval 15 miles on a true W. ¾ S. course, height of eye 20 feet: required the line of position, also the bearing of the sun by projection when the first altitude was taken, and the latitude and longitude when the second altitude was observed, assuming latitudes 47° 30′ N. and 47° 50′ N.

REMARKS ON THE DEGREE OF DEPENDENCE.

188. We have seen that the line of position is at right-angles to the direction of the object, hence the line of position itself can be obtained from *one* assumed latitude if the true bearing of the sun or celestial object observed be known. The Tables of the Sun's True Bearing, or Time Azimuth Tables, by BURDWOOD, for the parallels 60° to 30°, and the tables of DAVIS for the parallels of 30° to the equator give the true bearing of any celestial object whose declination does not exceed 23°. The tables of LABROSSE may also be used for the same purpose. By means of these tables the computation of a Sumner is shortened by one-half.

189. When the altitude of the celestial object is low, the circle of equal altitudes is large, the small portion of it comprised between two assumed latitudes is very nearly a straight line; but when the altitude is high, the circle is small, a small portion of it may be much curved, and the direction of the two extremities very different; that is, the bearing of the land and the sun's azimuth may be sensibly different for different parts of the same portion.* An error in the assumed latitudes has therefore most effect when the altitude is high and least when it is low, which last is always the preferable case.

190. If the sun is on the prime vertical at both observations, the lines of position will run North or South, and there will be no intersection.

If the latitude and declination are equal nearly, the lines of position will not change their direction sufficiently to depend upon their intersection.

When the body is near the prime vertical, errors in the latitude have the least effect upon the corresponding longitudes.

When the body is near the meridian, errors in the longitude have their least effect upon corresponding latitudes.

The value of the method depends entirely on the latitude assumed being near the truth.

191. When the coast trends parallel to the line of position, the distance of the ship from the shore is ascertained, though her absolute position is uncertain. When the observation is near noon, the line of position lies nearly E. and W., and the bearing of land in this direction is ascertained; but when the sun is E. or W., the line of position is nearly N. or S., and the position of the ship depends altogether upon the chronometer.

192. If there is an uncertainty in the altitude, draw on each side of the line of position lines parallel to it, and distant from it, the amount of the supposed uncertainty, and the position will be somewhere within this *belt* or linear space. Again, if a second altitude which gives another line of position is also doubtful, we project, as before, lines on each side this last line of position, and to the extent of the error of the altitude; we thus get a space

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[*] It will always be judicious to check the line of position, which is very easily done by means of the Time Azimuth Tables just referred to. By entering the tables with each assumed latitude, the declination of the object, and its given hour-angle, the true bearing for each latitude is found; then at each end of the line of position, project the line perpendicular to the true bearing just found; the point of crossing of the two perpendiculars will show whether or not the line of position is good.

(indicated by a quadrilateral) within which is the ship's position, and the area of the space is more circumscribed than either belt. The angle between the lines of position determines the form of the quadrilateral, as it changes its outline considerably for smaller or greater angles; its area, nevertheless, defines the limit of error, though the exact position of the point within it is unknown.

In the same manner, if there is an uncertainty in the Greenwich time, parallels may be drawn on each side of the line of position equal to this uncertainty. If now a small error in the chronometer is assumed, this error can be delineated around the quadrilateral just found, but as this gives no error in latitude we get a figure of different form—a hexagon, which determines the limit of error of the point, and gives an area of certitude within which the ship's position lies.

The error of the chronometer places the line of position too far East or West bodily, but does not alter its direction; hence, when there is but one chronometer on board, and its accuracy is doubtful, by placing a vessel on a line of position she might unsuspectingly be brought into danger, as, for instance, on the West Coast of Ireland, when supposed making for St. George's Channel. *The indications of an unverified chronometer must not be taken as giving a reliable line of position;* and in a vessel so circumstanced, special attention should be paid to the latitude and to the three L's generally—the parallel on which the ship is having been ascertained, it remains, if nearing the land, to feel the way by the lead, and keep a good look out.

A position obtained by two altitudes, with an interval between the observations, is affected to the extent of the errors of the dead reckoning during the interval, and by error in the altitudes.

The position determined by simultaneous altitudes of two stars, so selected that the angle between their verticals is such as to develope a good point of intersection, can only be affected to the extent of the errors of altitudes and those of the chronometer; and the seaman should lose no opportunity of observing them.

VARIATION BY AN AZIMUTH.

In this problem the **Error of the Compass** is required by computing the True Bearing of the Sun, and taking the difference between the True Bearing and the Bearing by an Azimuth Compass.

193. True Azimuth is the bearing of an object from the *true* North or South point, and is the azimuth found by calculation from the observed altitude or hour-angle of the body. It is in general simply called *The "Azimuth,"* but it is thus qualified as the *True* Azimuth to distinguish it from the *Magnetic* Azimuth, which is the bearing of the object from the compass North or South point, and which is found by direct observation with an instrument carrying a magnetic needle. The difference between the true and observed azimuth gives the entire correction of the compass--variation and deviation combined.

194. The Altitude Azimuth is the problem of computing the Azimuth of a heavenly body from an observation of its *altitude*, having also given its declination and the latitude of the *place of observation*.

195. The Time Azimuth is the problem of computing the Azimuth of a heavenly body (the sun being usually chosen) from noting by chronometer its hour-angle, having also given its declination and the latitude of the place of observation.

196. The best method of determining the "Sun's True Bearing," or Azimuth, is by what is known as "Time Azimuths;" it requires but one observer, and is very often available, whether the ship is in port or at sea, when the altitude cannot be observed on account of the horizon not being visible, the sun shining brightly all the while. The only objection to time azimuths has been the difficulty attendant on their calculation, accordingly, several contrivances have been adopted to reduce this labour. Amongst these—what are known as Time Azimuth Tables, or Tables of the Sun's True Bearing, have been published—those by BURDWOOD give the True Bearing of the Sun, or any celestial object whose declination does not exceed 23° for the parallels of 60° to 30°, and the Tables of DAVIS for the parallels of 33° to the Equator, calculated for every four minutes of apparent time when the altitude of such object is suitable.* Candidates at the Local Marine Board Examination are expected to be able to calculate the True Azimuth by means of either of these Tables.

197. Given the altitude, latitude, and declination of an object, to find the **True Azimuth.**

RULE LXXVII.

1°. *Add together the polar distance, the latitude, and the altitude,*† *take half the sum, and take the difference between the half sum and the polar dist.*

NOTE.—When the latitude is 0, suppose it to be of opposite name to the declination when finding the polar distance.

2°. *Add together the log. sec. of latitude, the log. sec. of altitude (rejecting tens) the log. cosines of the half sum and remainder; the sum (rejecting tens) is log. sine square of true azimuth* (Table 69, Raper). *Or half the sum of the four logs. is the log. sine of half of the true azimuth, which take out of the table* (Table XXIV, NORIE), *and double it; the result is the true azimuth.*

3°. *Write* S. before *the degrees, &c., of the true azimuth when the lat. is* N., *but write* N. before *the degrees, &c., of true bearing when the lat. is* S.; *also,*

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* In connection with Time Azimuths at sea BAIN & AINSLEY'S COMPASS CORRECTOR will be found invaluable. By means of it the true bearing of the ship's head is determined so that by comparing it with the bearing shown by the Standard Compass the deviation of the latter can be ascertained.

† The learner will observe that in this formulæ the pol. dist., lat., and alt., occur in the reverse order of that in Rule LXXIII, page 222 (finding hour-angle) in which the initials form the word *alp*. In finding the azimuth the initials form *pla*. The 2nd and 3rd terms take secants; the last two, cosines. By this arrangement the term which has to be taken from the half sum is always on the top—there being a difference in finding the remainder from that for finding the hour-angle.

write E. after *the degrees, &c., of true bearing when it is* A.M., *or the sun is* E. *of meridian, but write* W. after *the true bearing when the sun is* W. *of meridian, or it is* P.M.

NOTE.—The Azimuths are reckoned from the North and South points of the compass—*not* from East and West same as amplitudes.

(a) *When* latitude *is* 0°, *if* declination *is* N., *reckon the azimuth from the* South; *if* declination *is* S., *reckon the azimuth from the* North.

(b) *When* both latitude *and* declination *are* 0°, *the object moves on the prime vertical, or is* E. *while the altitude is* increasing *and* W. *while the altitude is* decreasing.

NOTE.—The logs. are taken out in these examples to the nearest second.

EXAMPLES.

EX. 1. Given the latitude 47° 46′ S.; declination 22° 27′ 22″ (or polar distance 67° 32′ 38″), true altitude 26° 44′ 8″ *increasing* (being A.M.)

Polar dist.	67° 32′ 38″		
Latitude	47 46 0	sec.	0·172533
Altitude	26 44 8	sec.	0·049103
Sum	142 2 46		
Half sum	71 1 23	cos.	9·512134
Half sum—p.d.	3 28 45	cos.	9·999199
			2)19·732969
	47° 20′ 7″	sine	9·866484
	2		470
True az.	N. 94 40 14 E.		7″ = 14

The sum of logs. (less 10 from index) 9·732969 being found in Table of log. sine squares (RAPER, Table 69) gives the corresponding arc, 94° 40′ 15″, whence true azimuth is N. 94° 40′ 15″ E. The *true* azimuth is here marked N. because the latitude is S., and E. because the altitude is *increasing*, it being A.M.

EX. 2. Latitude 38° 46′ N., declination 7° 41′ 56″ S., true altitude 27° 16′ 12″—P.M.

Polar dist.	97° 41′ 56″		
Latitude	38 46 0	sec.	0·108071
Altitude	27 16 12	sec.	0·051168
Sum	163 44 8		
Half sum	81 52 4	cos.	9·150627
Remainder	15 49 52	cos.	9·983207
			2)19·293073
	26° 18′ 15″	sine	9·646536
	2		474
True az.	S. 52 36 30 W.		15″ = 62

The sum of logs. (rejecting 10 from index), viz., 9·293073, being found in the log. sine square (Table 69, RAPER) gives the corresponding arc 52° 36′ 30″, whence the true azimuth is S. 52° 36′ 30″ W.

EX. 3. Latitude 28° 3′ N., declination 12° 39′ 50″ S., true altitude 25° 12′ 4″ + (A.M.)

Polar dist.	102° 39′ 50″		
Latitude	28 3 0	sec.	0·054267
Altitude	25 12 4	sec.	0·043438
Sum	155 54 54		
Half sum	77 57 27	cos.	9·319392
P. dist.—½ sum	24 42 23	cos.	9·958307
			2)19·375404
Half azimuth	29° 9′ 23″	sine	9·687702
	2		616
True az.	S. 58 18 46 E.		23″ = 86

The sum of the four logs. (rejecting 10 from the index) 9·375404, is the log. sine square of true azimuth; seek for log. in Table 69, RAPER, and the corresponding arc is 58° 18′ 46″, whence true azimuth is S. 58° 18′ 46″ E., the same as by NORIE's Tables.

EX. 4. Lat. 0°, declination 15° 2′ 27″ N., true altitude 24° 12′ 10″ —.

Polar dist.	105° 2′ 27″		
Latitude	0 0 0	sec.	0·000000
Altitude	24 12 10	sec.	0·039957
Sum	129 14 37		
Half sum	64 37 18	cos.	9·632046
Remainder	40 25 9	cos.	9·881568
			2)19·553571
Half azimuth	36° 44′ 6″	sine	9·776785
	2		
True az.	N. 73 28 12 W.		

The lat. is here assumed to be of the *opposite* name to declination, and pol. dist. is got by adding 90° to the declination. The true azimuth is marked N., the opposite name to the (assumed) lat., and W. because P.M.

EXAMPLES FOR PRACTICE.

In each of the following examples it is required to find the true azimuth. (The sign + means A.M., and the sign — means P.M.

1.	True altitude	7° 43′ 27″ +	Declination	11° 28′ 32″ N.	Latitude	51° 10′ N.
2.	„	28 30 53 +	„	21 56 45 S.	„	26 20 N.
3.	„	12 50 46 —	„	9 36 51 N.	„	15 47 S.
4.	„	7 15 55 —	„	12 14 38 S.	„	51 2 N.
5.	„	45 30 0 —	„	23 2 0 S.	„	0 0
6.	„	25 40 10 +	„	0 0 0	„	0 0

RULE LXXVIII.

1°. **To find the Greenwich date.**—(a) If the ship time is given—*Write down the mean time at ship expressed in astronomical time, to which apply the longitude in time*, adding *if longitude is* West, *but* subtracting *if* East: the result is mean time at Greenwich.

(b) If time by chronometer be given with its error on mean time at Greenwich—*To the time by chronometer* add *its error if* slow, *but* subtract *if* fast: the result is Greenwich mean time of observation.

2°. **To find the Polar Distance.**—*Take from* page II, Nautical Almanac, *the sun's declination, and reduce it to the Greenwich date* (Rule LIX, page 183), *also take out the sun's semidiameter from* page II of the month, Nautical Almanac.

If apparent time is given, use page I of the month in *Nautical Almanac.*

Find the Sun's Polar Distance.—(a) *By* subtracting *the declination from* 90° *when the latitude and declination are of the* same *name.*

(b) *By* adding 90° *when the latitude and declination are of* contrary *names* (Rule LXI, page 187).

3°. **To find True Altitude.**—*Correct observed altitude for index error* (±), *dip* (—), *refraction* (—), *parallax* (+), *semidiameter* (±), *and thus get the true altitude* (Rule LXIII, page 192).

4°. **To find the True Azimuth.**—*Add together the polar distance, the latitude and the altitude, take half the sum, and take the difference between the half sum and the polar distance.*

5°. *Add together the secant of latitude, secant of altitude (rejecting tens in the index), the cosine of the half sum, and cosine remainder; the* sum *(rejecting tens) is log. sine square of the* true azimuth (Table 69, RAPER). *Or, half the sum of the four logs. is the sine of half the true azimuth, which take out of the table* (Table XXIV, NORIE) *and* double it; *the result is the true azimuth* (Rule LXXVII, 2°, page 252).

6°. **To Name the True Azimuth.**—*Reckon the True Azimuth from* S. *when the latitude is* N., *but name it* N. *when latitude is* S., *towards* E. *when it is* A.M., *or when the altitude is* increasing, *but towards the* W. *when it is* P.M., *or the altitude is* decreasing (Rule LXXVII, 3°, page 252).

NOTE.—When latitude is 0° assume it to be S. if the observed bearing is Northerly, but assume it to be N. if the observed bearing is Southerly; this will obviate the necessity of having to subtract the true azimuth from 180°.

7°. **To find the Error of the Compass.**—*Reckon the* **true azimuth** *and the sun's* **bearing by compass** *from the* same *point of the compass*, North *or* South.

(a) *If* one *of the azimuths be expressed from the* North *and the other from the* South, *take the true azimuth from* 180°, *and the remainder will be in the* same *name* (N. *or* S.) *as the bearing by compass.*

Caution.—Be careful when taking the true bearing from 180°, *not to change* the **East** or **West** name; only the *North* or *South*.

(b) *If the bearing by compass be reckoned* from East *or* West towards *the* same point *as that from which the true bearing is reckoned*, subtract *the observed bearing from* 90°, *and reverse the position of the letters; but if the observed bearing is reckoned* towards *the* opposite *point* from *which the true bearing is reckoned*, add 90° *to the* observed bearing, *and it will be expressed for the* opposite *point to that from which it is reckoned when taken from* 90°.

Example.

Suppose the bearing by compass to be W. 18° 30′ N.

Then subtracting the observed azimuth from 90°, reverse the position of the letters; thus:—

90° 0′
W. 18 30 N.
N. 71 30 W.

The azimuth is thus reckoned from the North Pole.

Or, add 90° to the observed azimuth; thus:—

W. 18° 30′ N.
90
S. 108 30 W.

The azimuth in this case is reckoned from the South Pole.

(c) *When the Compass Bearing is* either East *or* West, *it is to be reckoned as* 90° *from* North *or* South, *according as the True Azimuth is* North *or* South.

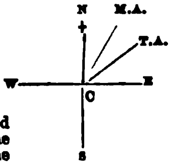
8°. *Under the True Azimuth write the sun's bearing by compass (both being reckoned from the same point of the compass*, N. *or* S., see note, 7°*) and take the* **difference** *of these bearings when measured* towards *the* same *point of the compass*, i.e., *if both are* East *or both* West; *but when measured* towards different *points*, i.e., *when* one *is reckoned towards* East *and the* other *towards* West, *take the* sum, *the result is* the error of the compass.

9°. **To Name the Error of the Compass.**—*Let the observer look at the two azimuths (or bearings) from the centre of the compass*, then if the true azimuth *is to the* right *of the* bearing by compass, *the* error *is* East, *but if the* true azimuth *is to the* left *of the* compass bearing *the* error *is* West.

Examples.

Ex. 1. Given true azimuth N. 44° 20′ E. and the sun's bearing by compass (or magnetic azimuth) N. 17° 10′ E.: required the error of compass.

True az. N. 44° 20′ E.
Mag. az. N. 17 10 E.
Error 27 10 E.

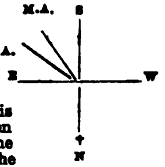


The observer being supposed looking from the centre of the compass in the direction of the magnetic azimuth, then the *true azimuth* lies to the *right* hand of the magnetic azimuth, whence the error of compass is to be marked *East*.

Ex. 2. Given true azimuth S. 70° 57′ E. the magnetic azimuth S.E. by E. ¾ E.: required the error of compass.

Mag. az. S.E. by E. ¾ E. = S. 64° 41′ E.

True az. S. 70° 57′ E.
Mag. az. S. 64 41 E.
Error 6 16 W.

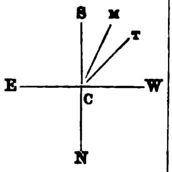


The error of compass is in this instance West, because when looking from the centre of the compass in the direction of the magnetic azimuth, the *true azimuth* is on the *left* hand of the magnetic.

Ex. 3. Given true azimuth S. 69° W., magnetic azimuth S. 47° W.: required the error of compass.

True az. S. 69° W.
Mag. az. S. 47 W.

Error 22 E.



The observer being supposed looking from the centre of the compass in the direction of the magnetic azimuth C M, then the true azimuth, C T, lies to the *right* hand of the magnetic azimuth, whence the error of the compass is *East*.

Ex. 4. True azimuth N. 50° 12′ E., and the observed azimuth N. 61° 50′ E.: required the correction of compass.

True azimuth N. 50° 12′ E.
Observed azimuth N. 61 50 E.

Error of compass 11 38 W.

The error of compass is here West, because the *true azimuth* is to the *left* hand of the observed azimuth, the observer being supposed to look from the centre of the compass in the direction of the magnetic azimuth.

Ex. 5. The true azimuth S. 62° 41′ E., and magnetic azimuth E.S.E.: required the error of compass.

True az. S. 62°41′ E.
S. 6 pts. E. = Mag. az. S. 67 30 E.

Error of compass 4 49 E.

Here the error of compass is East, since the *true azimuth* is on the *right* of the magnetic azimuth, the observer looking from the centre of the compass in the direction of the magnetic azimuth.

Ex. 6. The true azimuth S. 82° 50′ W., and magnetic azimuth W. 15° N.

True az. S. 82°50′ W.
W. 15° N. = Mag. az. S. 105 0 W.

Error of compass 22 10 W.

The error of compass is West, the *true azimuth* being to the *left of magnetic*. 90° is *added* to the compass bearing in order to reckon it from the same point as the true azimuth; thus, from S. to W. is 90°, and from W. to W. 15° N. is 15° more; hence magnetic azimuth is S. 105° W.

Ex. 7. True azimuth N. 72° E., magnetic azimuth East.

True azimuth N. 72°E.
Mag. azimuth East = N. 90 E.

Error of compass 18 W.

The magnetic azimuth, E., is reckoned as 90° from N., because the true azimuth is reckoned from N.

Ex. 8. The true azimuth is S. 76° W., and the magnetic azimuth West.

True azimuth S. 76° W.
Mag. azimuth West = S. 90 W.

Error of compass 14 0 W.

The magnetic azimuth, W., is reckoned as 90° from S., because the true azimuth is reckoned from S.

Ex. 9. The true azimuth S. 90° 33′ E., and magnetic azimuth N. 81° 20′ E.: find the error of compass.

True azimuth S. 90°33′ E.
180 0

or N. 89 27 E.
Mag. azimuth N. 81 20 E.

Error of compass 8 7 E.

The *true azimuth* being reckoned from S., while the magnetic azimuth is expressed from N., the true is subtracted from 180°, in order to reckon it from the same point as the magnetic azimuth, viz., from N.

Ex. 10. The true azimuth N. 69° 39′ W., and magnetic azimuth S. 93° 30′ W.: find the error of compass.

True azimuth N. 69°39′ W.
180 0

or S. 110 21 W.
Mag. azimuth S. 93 30 W.

Error of compass 16 51 E.

The *true azimuth* is here taken from 180°, in order to reckon it from the same point as the magnetic azimuth.

Ex. 11. True azimuth S. 36° W., magnetic azimuth S. 9° E.

True azimuth S. 36°W.
Mag. azimuth S. 9 E.

Error of compass 45 E.

Add when one E. and the other W.

Ex. 12. True azimuth N. 68° W., observed azimuth N. 5° E.

True azimuth N. 68°W.
Obs. azimuth N. 5 E.

Error of compass 73 W.

Add when one E. and the other W.

Ex. 13. True azimuth N. 49° E., magnetic azimuth N. 3° W.

True azimuth N. 49°E.
Mag. azimuth N. 3 W.

Error of compass 52 E.

Add when one E. and the other W.

Ex. 14. True azimuth S. 50° E., magnetic azimuth S. 8° W.

True azimuth S. 50°E.
Mag. azimuth S. 8 W.

Error of compass 58 W.

Add when one E. and the other W.

10°. **To find the Deviation.**—*Next place the* variation *below the* error of compass, then

(a) *If they are of* like names, i.e., *are both* East *or both* West, *take their difference.*

(b) *But if they* have unlike names, i.e., *if one is* East *and the other is* West, *take the* sum.

The sum *or* difference *(as the case may be) is the* deviation.

11°. **To Name the Deviation.**—*The* **deviation** *is of the* **same name** *as the error* UNLESS *the* **error** *has been subtracted from the* **variation,** *in which case the* **deviation** *is of a* **contrary name** *to the* **error,** i.e., *the* **deviation** *is* E. *when the* **error** *is* W., but W. *when* **error** *is* E. (see 8° and 9° of Rule LXV, and examples illustrating the rule, page 200.

TO FIND DEVIATION BY TIME AZIMUTHS.

RULE LXXIX.

1°. **To find the Greenwich Date.**—(a) If mean time at ship is given.—*With ship time (expressed astronomically) and longitude find the Greenwich date* (Rule LVIII, page 179).

(b) If time by chronometer is given with its error on mean time at Greenwich.—*To the time by chronometer* add *its error if* slow, *and* subtract *if* fast: the result is mean time at Greenwich.

2°. **To find Declination and Equation of Time.**—*Take from* page II, Nautical Almanac, *the sun's declination and reduce it to the Greenwich date* (Rule LIX, page 183); *also take out of* page II *the Equation of Time and reduce it to Greenwich date* (Rule LXII, page 189), *noting whether it is to be* added to *or* subtracted from *mean time.*

NOTE 1.—Be careful to remember that the Equation of Time must be applied as directed at the top of the column on page II, *Nautical Almanac;* that is, the *contrary* way to that used when *working the chronometer.*

NOTE 2.—At the examination the candidate is required to calculate the true azimuth both from the altitude and by the "Time Azimuth Tables," and as the Green. date and reduced declination are required to be found in alt.-azimuth questions it is unnecessary again to find the Green. date and reduced declination as directed in Rule, 1° and 2°. The equation of time must be found as directed in 2°.

To find Apparent Time at Ship.—*To Greenwich mean time apply the longitude in time by*

Subtracting *if* longitude *is* West.
Adding *if* longitude *is* East.

The result is mean time at ship.

3°. *To mean time at ship apply the Equation of Time as found by* No. 2°; the result *is apparent time at ship, which, if* less *than* 12^h, *that is, if* P.M., *is the* *quantity with which to enter the "Time Azimuth Tables;" but if apparent time* exceeds 12^h, *that is, if it is* A.M. *at ship, deduct* 12^h, *and enter the Tables with the remainder.*

4°. **To find the True Azimuth.**—*In the Tables* (BURDWOOD's or DAVIS') *find the degree of latitude at the top, also declination* same *or* different *names, at the top of its proper column, and look for the apparent time, which is found in the* left hand margin *of the page if* A.M.; *but in the* right hand *column if* P.M. *at ship; then in a line with the time, and under the degree of the declination is found the* **Sun's True Bearing, or Azimuth.**

NOTE.—In BURDWOOD's Tables there are 10 pages to each latitude (30° to 60°)—the first 5 or 6 pages are to be entered when the latitude is of the *same* name as the declination; the remaining portion of them are to be entered when the latitude and declination are of *contrary* names. In DAVIS' Tables (lat. 0° to 30°) the azimuth is given in precisely the same form as in BURDWOOD's.

5°. **To Name the Sun's True Bearing, or Azimuth.**—The true azimuth is to be named—

(a) In North latitude—

From N. towards E. in the morning,
From N. towards W. in the afternoon.

(b) In South latitude—

From S. towards E. in the morning,
From S. towards W. in the afternoon.

NOTE.—The learner must carefully note that in this problem the azimuth is named the contrary way to the alt.-azimuth, that is to say, it is named from the point of the same name as the latitude, whereas in the alt.-azimuth question it is reckoned from the opposite point to the latitude.

The following examples will illustrate this part of the rule:—

EXAMPLES.

EX. 1. Lat. 50° N., decl. 11° S., app. time at ship 4^h 12^m P.M.: required the true azimuth by *Burdwood's Tables.*

In the Tables (page 210, *Burdwood's Tables*) find the latitude (50°) at the top of the page, and the declination (11° S.)—*contrary name to latitude*—at the head of its proper column; then under this, and in a line with the apparent time 4^h 12^m found in the *right* hand column headed "Apparent time P.M.," we have the true azimuth 117° 57′. The latitude being North, prefix N. to it; and as it is P.M. write W.; hence true azimuth is N. 117° 57′ W.

$$\left.\begin{array}{l}\text{Latitude } 50^\circ\text{ N., and declination } 11^\circ\text{ S.}\\ \text{(Declination \textit{contrary name to} Latitude)}\\ \text{Apparent time } 4^h\ 12^m\text{ P.M.}\end{array}\right\}\text{ give in \textit{Burdwood's Tables}, page 210,}$$

True azimuth N. 117° 57′ W.

EX. 2. Lat. 50° N., decl. 11° S., app. time at ship 7^h 48^m A.M.: required the true azimuth by inspection by *Burdwood's Tables.*

Latitude 50° at the top of page 210, *Burdwood's Tables,* and declination 11° (declination *contrary name* to latitude) at the top of its proper column; under this, and in a line with

$7^h\ 48^m$ found in the *left* hand column under the head "Apparent Time A.M." gives the true azimuth 117° 57′. The latitude being North prefix N. to it; and as it is A.M. write E. after it; hence the true azimuth is N. 117° 57′ E.

Latitude 50° N., and declination 11° S.
(Declination *contrary name to* Latitude) } give in *Burdwood's Tables*, page 210,
Apparent time $7^h\ 48^m$ A.M.

True Azimuth N. 117° 57′ E.

Ex. 3. Lat. 50° N., decl. 11° N., app. time $5^h\ 12^h$ P.M.: required the true azimuth by inspection by *Burdwood's Tables.*

Latitude 50° at the top of page, and declination 11° (decl. *same name* as lat.) at the top of its proper column; under this, and in a line with $5^h\ 12^m$, found in the *right* hand column under head "Apparent Time P.M." gives the true azimuth 92° 1′. The latitude being North, prefix the N. to it; and as it is P.M. write W. after it; hence the true azimuth is N. 92° 1′ W.

Latitude 50° N., and declination 11° N.
(Declination *same name as* Latitude) } give in *Burdwood's Tables*, page 204,
Apparent time $5^h\ 12^m$ P.M.

True Azimuth N. 92° 1′ W.

Ex. 4. Lat. 50° N., decl. 11° N., app. time $6^h\ 48^m$ A.M.: required the true azimuth by inspection by *Burdwood's Tables.*

Latitude 50° at the top of page, and declination 11° (declination *same name* as latitude) at the top of its proper column; under this, and in a line with $6^h\ 48^m$, found in the *left* hand column under head "Apparent time A.M." gives the true azimuth 92° 1′. The latitude being North prefix N. to it; and as it is A.M. write E. after it; hence the true azimuth is N. 92° 1′ E.

Latitude 50° N., and declination 11° N.
(Declination *same name as* Latitude) } give in *Burdwood's Tables*, page 204,
Apparent time $6^h\ 48^m$ A.M.

True Azimuth N. 92° 1′ E.

6°. To find the Error of Compass and the Deviation.—The error of the compass and the deviation are found precisely in the same way as in the alt.-azimuth question.

EXAMPLES.

Ex. 1. 1887, May 19th, $3^h\ 7^m\ 57^s$ P.M., mean time at ship, latitude 41° 53′ N., longitude 60° 16′ W., sun's bearing by compass S. 104° 40′ W., observed altitude sun's L.L. 43° 56′ 7″, height of eye 18 feet, index correction 0′: required the true azimuth and error of the compass from the altitude, and also by "Time Azimuth Tables;" and supposing the variation to be 17° 10′ W.: required the deviation of the compass for the position of the ship's head.

Ship date (M.T.), May	19^d	3^h	7^m	57^s
Long 60° 16′ W., in time	+	4	1	4
Green. date (M.T.), May	19	7	9	1

By *Raper:* Dip − 4′ 10″, refr. − 1′ 1″, par. + 6″, semid. + 15′ 50″, true altitude 44° 6′ 52″.

Obs. alt. sun's L.L.	43°	56′	7″
Dip	−	4	4
	43	52	3
Corr. altitude	−		53
	43	51	10
Semidiameter	+	15	50
True altitude	44	7	0

Polar dist.	70° 10′ 38″	
Latitude	41 53 0	sec. 0·128132
Altitude	44 7 0	sec. 0·143922
	156 10 38	
	78 5 19	cos. 9·314707
	7 54 41	cos. 9·995847
		2)19·582608
		sine 9·791304

Decl., page II, N.A.		H.D.
19th, noon	19° 45′ 32″ N. +	32″·20
Correction	3 50	7·15
Red. decl.	19 49 22 N.	16100
	90 0 0	3220
		22540
Polar dist.	70 10 38	
		6,0)23,0·2300
	Correction	+ 3 50·2

Half azimuth	38° 12′ 11″
	2
True azimuth	S. 76 24 W.
Observed azimuth	S. 104 40 W.
Error of compass	28 16 W., because *true* azimuth is left of observed azimuth.
Variation	17 10 W.
Deviation	11 6 W., because the deviation is to left of variation.

By *Raper:* Sum of logs. 9·582632, whence true azimuth S. 76° 24′ 30″ W., error of compass 28° 15′ 20″ W., deviation 11° 5′ 20″ W.

By Time Azimuth Tables.

M.T. ship, May 19th	$3^h\ 7^m 57^s$
Equation time	+ 3 45
A.T. at ship, May 19th	3 11 42

Eq. Time, page II, N.A.			H.D.
19th, noon	$3^m 45^s·8$		$0^s·110$
Correction	— 0·8		7·15
Red. Eq. time	3 45·0	Corr.	·78650
	(*Add* to M.T.)		

Latitude 42° N., and declination 20° N.
(Latitude *same name as* Declination)
Apparent time at ship $3^h\ 12^m$ P.M.

True azimuth	N. 103° 25′ W.
	180 0
Or True azimuth	S. 76 35 W.
Mag. azimuth	S. 104 40 W.
Error of compass	28 5 W.
Variation	17 10 W.
Deviation	10 55 W.

Fig. 59.

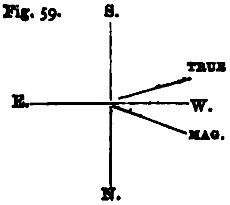
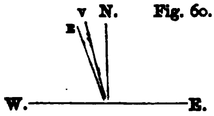


Fig. 60.



Ex. 2. 1887, June 14th, P.M. at ship, latitude 31° 10′ N., longitude 134° 40′ W., sun's bearing by compass West, observed altitude sun's L.L. 49° 0′ 10″, height of eye 18 feet, time by chronometer June $14^d\ 12^h\ 0^m\ 8^s$, mean time at Greenwich: required the true azimuth and error of the compass from the altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 25° 50′ E.: required the deviation for the position of the ship's head.

M.T. at Green., June $14^d\ 12^h\ 0^m\ 8^s$.

By *Raper:* Dip — 4′ 10″, refr. — 51″, par. + 6″, semid. + 15′ 47″, true altitude 49° 11′ 2″.

Obs. alt. sun's L.L.	49° 0′ 10″
Dip	— 4 4
	48 56 6
Corr. altitude	— 44
	48 55 22
Semidiameter	+ 15 47
True altitude	49 11 9

Polar dist.	66° 42′ 19″	
Latitude	31 10 0	sec. 0·067696
Altitude	49 11 9	sec. 0·184683
	147 3 28	
	73 31 44	cos. 9·452602
	6 49 25	cos. 9·996913
		2)19·701894
	45° 11′ 36″	sine 9·850947
	2	
	S. 90 23 12 W.	

Decl., page II, N.A.		H.D.
14th, noon	23° 16′ 11″ N. +	7·49
Correction	+ 1 30	12
Red. decl.	23 17 41 N.	6,0)8,9·88
	90	
		+ 1 29·88
Polar dist.	66 42 19	

By *Raper*: Sum of logs. 9·701906, error of compass 0° 23′ E., dev. 25° 27′ W.

True azimuth	S. 90° 23′ W.	
Obs. azimuth West =	S. 90 0 W.	
Error of compass	0 23 E.,	because true azimuth is to
Variation	25 50 E.	right of obs. azimuth.
Deviation	25 27 W.,	because the error is to the left of the variation.

M.T. at Green.	June 14ᵈ 12ʰ 0ᵐ 8ˢ			
Long. 134° 40′ W.	— 8 58 40			
M.T. at ship	June 14 3 1 28			
Eq. of Time	— 1			
A.T. at ship	June 14 3 1 27			

Eq. of Time, page II, N.A.		H.D.
14th, noon	0ᵐ 5ˢ·7 —	0·524
Correction	— 6·3	12
Red. Eq.	0 0·6	6·288
(*Subt.* from M.T.)		

Latitude 31° N., and declination 23° N.
(Latitude *same name as* Declination)
App. time ship 3ʰ 0ᵐ P.M.

True azimuth	N. 90° 1′ W.
Mag. azimuth W. =	N. 90 0 W.
Error of compass	0 1 W.
Variation	25 50 E.
Deviation	25 51 W.

Ex. 3. 1887, February 12th, mean time at ship 4ʰ 8ᵐ P.M., latitude 27° 47′ S., longitude 94° 45′ E., the sun's bearing by compass W. by S. ½ S., obs. alt. sun's L.L. 34° 0′ 45″, height of eye 21 feet: required the true azimuth and error of the compass from the altitude, and also by "Time Azimuth Tables;" and supposing the variation to be 9° 30′ W.: required the deviation of the compass for the position of the ship's head.

Ship date (M.T.)	Feb.	12ᵈ 4ʰ 8ᵐ 0ˢ
Long. 94° 45′ E., in time		— 6 19 0
Green. date (M.T.)	Feb.	11 21 49 0
Time from noon (*nearest*)		12 2 11

By *Raper*: Dip — 4′ 25″, refr. — 1′ 26″, par. + 7″, semid. + 16′ 14″, true altitude 34° 11′ 15″.

Obs. alt. sun's L.L.	34° 0′ 45″
Dip	— 4 23
	33 56 22
Corr. altitude	— 1 17
	33 55 5
Semidiameter	+ 16 14
True altitude	34 11 19

Polar dist.	76° 16′ 34″	
Latitude	27 47 0	sec. 0·053196
Altitude	34 11 19	sec. 0·082393
	138 14 53	
	69 7 26	cos. 9·551875
	7 9 8	cos. 9·996608
		2)19·684072
	44° 2′ 2″	sine 9·842036
	2	
	N. 88 4 4 W.	

Decl., page II, N.A.		H.D.
12th, noon	13° 41′ 36″ S. —	49″·90
Correction	+ 1 50	2·2
Red. decl.	13 43 26 S.	9980
	90 0 0	9980
Polar dist.	76 16 34	6,0)10,9·780
		1 49·8

True azimuth	N. 88° 4′ 4″ W.
	180 0 0
True azimuth	S. 91 55 56 W.
Observed azimuth	S. 73 7 30 W. (= W. by S. ½ S.)
Error of compass	18 48 26 E.
Variation	9 30 0 W.
Deviation	28 18 26 E.

By *Raper:* Sum of logs. 9·684076, true azimuth N. 88° 4′ 5″ W., error of compass 18° 48′ 25″ E., deviation 28° 18′ 25″ E.

M.T. ship, Feb. 12th	$4^h\ 8^m\ 0^s$
Equation time	— 14 28
App. T. ship, Feb. 12th	3 53 32

Eq. Time, page II, N.A.		H.D.
12th, noon	$14^m 26^s$·76 —	0·039
	+ 0·86	2·2
Red. Eq. time	14 27·62	78
		78
(*Subt.* from M.T.)		
	Corr.	·858

Latitude 28° S., and declination 14° S.
(Latitude *same name as* Declination)
Apparent time at ship $3^h\ 52^m$ P.M.

True azimuth	S. 91° 56′ W.
Mag. azimuth	S. 73 8 W.
Error of compass	18 48 E.
Variation	9 30 W.
Deviation	28 18 E.

Ex. 4. 1887, September 1st, A.M. at ship, latitude 47° 50′ N., longitude 166° 21′ E., sun's bearing by compass E. by S. ½ S., obs. alt. sun's L.L. 39° 50′ 40″, index corr. — 1′ 6″, height of eye 17 feet, time by chronometer August $31^d\ 10^h\ 29^m\ 19^s$, mean time at Greenwich: required the true azimuth and error of the compass from altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 5° 10′ W.: required the deviation for the position of the ship's head.

M.T. at Green.,	Aug. $31^d\ 10^h 29^m 19^s$
	10^h·5

By *Raper:* Ind. corr. — 1′ 6″, dip — 4′ 5″, refr. — 1′ 10″, par. + 7″, semid. + 15′ 53″, true altitude 40° 0′ 19″.

Obs. alt. sun's L.L.	39° 50′ 40″
Index correction	— 1 6
	39 49 34
Dip	— 3 57
	39 45 37
Corr. altitude	— 1 2
	39 44 35
Semidiameter	+ 15 53
True altitude	40 0 28

Polar dist.	81° 28′ 58″	
Latitude	47 50 0	sec. 0·173090
Altitude	40 0 28	sec. 0·115795
	169 19 26	
	84 39 43	cos. 8·968632
	3 10 45	cos. 9·999331
		2)19·256848
	25° 9′ 10″	sine 9·628424
	2	
	50 18 20	

Decl., page II, N.A.		H.D.
Aug. 31st, noon	8° 40′ 30″ N. —	54·07
Corr. $10^h 29^m$	— 9 28	10·5
Red. decl.	8 31 2 N.	27035
	90 0 0	54070
Polar dist.	81 28 58	6,0)56,7·735
		9 27·7

True azimuth	S. 50° 18′ E.	
Observed azimuth	S. 70 19 E. (E. by S. ¾ S.)	
Error of compass	20 1 E.,	because true azimuth to *right* of observed.
Variation	5 10 W.	
Deviation	25 11 E.,	because error to *right* of var.

By *Raper:* Sum of logs. 9·256947, true azimuth S. 50° 18′ 42″ E., error of compass 20° 0′ 3″ E., deviation 25° 10′ 3″ E.

M.T. Green.	Aug.	$31^d 10^h 29^m 19^s$
Long. 166° 21′ E.		+ 11 5 24
M.T. ship	Aug.	31 21 34 43
Equation of time		— 7
App. T. ship	Aug.	31 21 34 36
		— 12
		9 34 36

Eq. Time, page II, N.A.		H.D.
31st, noon	$0^m 14^s$·85	0·772
Correction	— 8·11	10·5
Red. Eq. time	0 6·74	3860
		7720
(*Subt.* from M.T.)		8·1060

Latitude 48° N., and declination 9° N.
(Latitude *same name as* Declination)
Apparent time at ship $9^h 36^m$ A.M.

True azimuth	N. 130° 7′ E.	
	180 0	
Or True azimuth	S. 49 53 E.	
Mag. azimuth	S. 70 19 E.	
Error of compass	20 26 E.	
Variation	5 10 W.	
Deviation	25 36 E.	

Ex. 5. 1887, June 1st, A.M. at ship, lat. 60° N., long. 40° 20′ W., sun's bearing by compass S. ½ W., obs. alt. sun's L.L. 44° 48′ 50″, index corr. + 3′ 17″, height of eye 18 feet, time by chronometer June $1^d 0^h 21^m 20^s$, mean time at Greenwich: required the true azimuth and error of the compass from altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 51° 15′ W.: required the deviation for the position of the ship's head.

Green. date June $1^d 0^h 21^m 20^s$, true altitude (NORIE) 45° 3′ 0″, "Var. in 1^h" of decl. 20″·46 ÷ $⅓^h$ = 7″, which, *added* to decl., June 1st at noon, viz., 22° 3′ 10″ N., gives the red. decl. 22° 3′ 17 N., pol. dist. 67° 56′ 43″, sum of logs. 19·214733, true azimuth S. 47° 46′ E.

True azimuth	S. 47° 46′ E.	
Obs. azimuth	S. 5 37½ W. (= S. ½ W.)	
Error of compass	53 23½ W.,	because true azimuth *left* of observed azimuth.
Variation	51 15 W.	
Deviation	2 8½ W.,	because error is *left* of variation.

By *Raper:* True alt. 45° 2′ 52″, sum of logs. 9·214857, true azimuth S. 47° 46′ 45″ E., error of compass 53° 24′ 15″ W., deviation 2° 9′ 15″ W.

M.T. at Green.	June $1^d\ 0^h21^m20^s$	Eq. of Time, page II, N.A.		H.D.
Long. 40° 20′ W.	− 2 41 20	1st, at noon	2^m28^s·2 −	⅓)0·370
			− 0·1	
M.T. at ship	May 31 21 40 0			Corr. 0·123
Eq. of time	+ 2 28	Red. Equation	2 28·1	
App. T. ship	May 31 21 42 28			
	12	(To be *added* to M.T.)		
	9 42 28			

Latitude 60° N., and declination 22° N.
(Latitude *same name as* Declination)
App. time at ship $9^h\ 44^m$ A.M.

True azimuth	N. 132° 42′ E.
	180 0
or, True azimuth	S. 47 18 E.
Mag. azimuth	S. 5 37½ W.
Error of compass	52 55½ W.
Variation	51 15 W.
Deviation	1 40½ W.

Ex. 6. 1887, March 20th, at $10^h\ 50^m$ A.M., mean time at ship, lat. 0°, long. 172° 9′ W., sun's bearing by compass East, obs. alt. sun's L.L. 36° 24′, height of eye 15 feet: required the true azimuth and error of the compass from the altitude, and also by "Time Azimuth Tables;" and supposing the variation to be 24° W.: required the deviation of the compass for the position of the ship's head.

Ship date (M.T.)	March $19^d\ 22^h50^m\ 0^s$	Decl., page II, N.A.		H.D.
Long. 172° 9′ W.	+ 11 28 36	20th, noon	0° 10′ 11″ S.	59·25
Green. date	March 20 10 18 36	Corr. for 10^h·31	10 11	10·31
	or, 10·31	Red. decl.	0 0 0	5925
				17775
				59250
				6,0)61,0·8675
				10 11

M.T. ship	March $19^d\ 22^h50^m\ 0^s$	Eq. T., page II, N.A.		H.D.
Equation of Time	− 7 30	20th, noon	7^m37^s·8	0·747
App. T. at ship	March 19^d 22 42 30	Corr.	− 7·7	10·31
	12	Red. Eq. Time	7 30^s·1	7·70157
	10 42 30	(*Subt.* from M.T.)		

Latitude 0°, and declination 0°
App. T. at ship $10^h\ 42^m$ A.M. } 90°

Lat. 0° and decl. 0°, and A.M., the sun's true bearing is East, and since the observed bearing is also East, the error of compass is 0° 0′, and deviation is equal in amount to variation with the name reversed; hence, the deviation is 24° E. The example need not be calculated beyond the reduced declination.

Examples for Practice.

In each of the following examples it is required to find the true azimuth, also the error of the compass and deviation for the position of the ship's head at the time of observation, both from the altitude and by "Time Azimuth Tables."

No.	Civil Date, 1887.	M.T. ship.	Latitude.	Longitude.	Sun's bearing by compass.	Obs. alt. sun's L.L.	Ht. of eye.	Variation.
1	January 24th......	8h29m58s A.M.	26° 5′ S.	49° 2¼′ W.	E. by N............	38°23′ 10″	16	4°36′ E.
2	February 28th ...	3 15 10 P.M.	38 46 N.	96 58½ W.	S. 42° 30′ W.......	26 57 14	17	11 30 E.
3	March 27th.........	4 6 40 P.M.	4 22 N.	53 7 E.	W. by N.	29 30 50	20	3 30 W.
4	April 3rd............	5 14 32 P.M.	49 59 N.	153 36 E.	West	11 43 0	17	9 10 E.
5	May 27th............	9 3 20 A.M.	55 0 N.	1 33 W.	S. 61° 45′ E.	43 8 51	18	15 45 W.
6	June 15th	8 54 35 A.M.	43 3 S.	147 28¾ E.	N.E. ¼ E.	11 2 10	22	11 10 E.
7	July 31st............	8 52 51 A.M.	38 18 N.	63 28½ W.	S. 75° 20′ E.	43 24 58	18	8 50 W.
8	August 23rd	5 55 20 A.M.	51 10 N.	135 34½ W.	N. 66° 20′ E.	7 38 0	15	25 30 E.
9	September 1st ...	9 34 33 A.M.	47 50 N.	165 19 E.	E. by S. ¾ S.	39 49 10	17	5 30 W.
10	November 25th ...	3 57 10 P.M.	39 58 S.	53 19½ W.	W. ½ N.	33 51 0	14	9 22 E.
11	December 24th ...	3 30 0 P.M.	36 4 N.	43 40 W.	S.W. ¾ W.........	12 35 0	17	24 30 W.
12	June 14th	8 9 2 A.M.	60 0 N.	47 19 W.	E. ½ N.	35 49 15	16	17 0 W.

13. 1887, January 6th, P.M. at ship, lat. 47° 46′ S., long. 33° 31′ E., sun's bearing by compass N. 84° 40′ W., obs. alt. sun's L.L. 26° 37′ 27″, height of eye 28 feet, time by chronometer Jan. 6d 2h 49m 30s mean time at Greenwich: required the true azimuth and error of the compass; and supposing the variation to be 7° 50′ E.: required the deviation for the position of the ship's head, both from the altitude and by "Time Azimuth Tables."

14. 1887, April 14th, A.M. at ship, lat. 48° 14′ N., long. 157° 31′ W., the sun's bearing by compass E. by S. ½ S., obs. alt. sun's L.L. 35° 33′ 40″, height of eye 30 feet, when a chronometer showed April 14d 7h 26m 30s mean time at Greenwich: required the true azimuth and error of the compass; and supposing the variation to be 19° 40′ E.: required the deviation for the position of the ship's head, both from the altitude and by "Time Azimuth Tables."

15. 1887, January 29th, P.M. at ship, lat. 42° 26′ N., long. 49° 18′ W., the sun's bearing by compass W. 9° 10′ S., obs. alt. sun's L.L. 13° 38′ 46″, height of eye 16 feet, time by chronometer Jan. 29d 6h 53m 47s mean time at Greenwich: required the true azimuth and error of the compass; and supposing the variation to be 20° 30′ W.: required the deviation for the position of the ship's head, both from the altitude and by "Time Azimuth Tables."

16. 1887, February 11th, A.M. at ship, lat. 53° 12′ N., long. 5° 13½ W., sun's bearing by compass S.E. ¾ S., obs. alt. sun's L.L. 12° 10′ 0″, height of eye 12 feet, time by chronometer Feb. 10d 21h 33m 26s mean time at Greenwich: required the true azimuth and error of the compass; and supposing the variation to be 19° 15′ W.: required the deviation for the position of the ship's head, both from the altitude and by "Time Azimuth Tables."

17. 1887, February 1st, P.M. at ship, lat. 33° 51′ S., long. 20° 37′ E., sun's bearing by compass N. 70° 50′ W., obs. alt. sun's L.L. 39° 56′ 10″, height of eye 18 feet, time by chronometer February 1d 2h 22m 23s mean time at Greenwich: required the true azimuth and error of the compass; and supposing the variation to be 29° 40′ W.: required the deviation for the position of the ship's head, both from the altitude and by "Time Azimuth Tables."

18. 1887, February 20th, A.M. at ship, lat. 60° N., long. 166° 32′ E., sun's bearing by compass S. ½ W., obs. alt. sun's L.L. 11° 21′ 10″, height of eye 20 feet, time by chronometer February 19d 10h 19m 11s mean time at Greenwich: required the true azimuth and error of the compass; and supposing the variation to be 30° W.: required the deviation for the position of the ship's head, both from the altitude and by "Time Azimuth Tables."

ON FINDING THE LATITUDE BY REDUCTION TO THE MERIDIAN.

198. The latitude of a place is most simply determined by observation of the meridian altitude of a known heavenly body. When such an observation cannot be obtained by reason of the state of the weather, the altitude of the body may often be obtained a little before or a little after its meridian passage. And if at the time of observing such an altitude near the meridian, the hour-angle of the body is known, we may find by computation very nearly the difference of altitude by which to reduce the observed to the Meridian altitude. The correction is called the "Reduction to the Meridian." This method, in point of simplicity, is little inferior to the meridian altitude, to which it is next in importance. The latitude may also be determined by a direct process, deduced from spherical trigonometry. The former is the method used in the following pages. The term "near the meridian" implies a meridian distance limited according to the latitude and declination, and also the degree of precision with which the time is known (see RAPER, Table 47).*

If the time by watch with its error on apparent time at ship is given.

RULE LXXX.

1°. **To find the Apparent Time at Ship.**—*To the time shown by the watch, expressed astronomically, apply the error of the watch for apparent time,*† adding *when the watch is* slow *(rejecting* 24ʰ *when the sum exceeds* 24ʰ, *and putting the day one forward)*, subtracting *when the watch is* fast *(increasing the time shown by watch by* 24ʰ, *if necessary, and putting the day one back).*

2°. *Next turn into time the difference of longitude made since the error of the watch was determined,* adding *when the difference of longitude is* East, subtracting *when the difference of longitude is* West; the result is apparent time at ship when the observation was made.‡

3°. **To find the Time from Noon.**—*If* P.M. *at ship the apparent time at ship is the time from noon; when it is* A.M. *(reckoning from the preceding noon) subtract apparent time at ship from* 24ʰ*; the remainder is the time from noon.*

---

* This Table shows the limits of the method of "Reduction to the Meridian" for common practice at sea, or how long before or after the time of meridian passage the sun's altitude may be observed, so that the reduction shall not be more in error than 2′ when the time is 1ᵐ in error.

† The error of chronometer for *apparent time* at place should be noted when the morning sights are taken for determining the longitude. This, with the diff. long. made in the interval between this last time and the time of observing the ex-meridian altitude, will give the apparent time at ship. If the ship has not changed her meridian since the time of morning sights, the result obtained by applying the error of chronometer is, of course, the apparent time at ship.

‡ The reason for this rule will appear on considering that if a watch is set to the time at any given meridian, it will be *slow* for any meridian to the *eastward*, but *fast* for any meridian to the *westward*, at the rate of 1ᵐ for 15′ diff. long., since the sun comes to the *easterly* meridian earlier, and to the *westerly* meridian later.

EXAMPLES.

Ex. 1. Suppose it is P.M. at ship, and the watch when *corrected* shows January $2^d\ 0^h\ 16^m\ 56^s$ (see Ex. 1 following): then the time from noon is $16^m\ 56^s$ past noon of the 2nd.

Ex. 2. Again, suppose it is A.M. at ship, and the watch when *corrected* indicates Feb. $5^d\ 23^h\ 37^m\ 16^s$ (see Ex. 2 following): then we have

$$\left.\begin{array}{r} 24^h\ 0^m\ 0^s \\ 23\ 37\ 16 \\ \hline 22\ 44 \end{array}\right\}$$

In this instance it is $22^m\ 44^s$ before noon of the 6th.

4°. **To find Greenwich Apparent Time.**—*With apparent time at ship and longitude find Greenwich date in apparent time* (Rule LVIII, page 179).

5°. *Take out of* Nautical Almanac, page I, *the declination, and reduce it to the Greenwich date* (Rule LIX, page 183).

If the time by chronometer is given, with the error on mean time at Greenwich.

(a) *To the time by chronometer* apply *its error on Greenwich mean time,* adding *if* slow *and* subtracting *if* fast; *the* result *is* mean time at Greenwich.

(b) *Write down the Equation of time,* taken from page II of the month in the Nautical Almanac, *and correct it for Greenwich mean time, and mark it* "added to" *or* "subtracted from" *mean time, as directed at the heading of the column in* page II of Nautical Almanac (Rule LXII, page 188); *also take out the sun's declination from* page II, Nautical Almanac, *and correct* it *also for Greenwich time* (Rule LIX, page 183).

(c) *Under mean time at Greenwich, found as above in* (a), *write down longitude in time,* adding *if* East, *and* subtracting *if* West: *the* result *will be* mean time at ship.

(d) *To mean time at ship, just found in* (c), *apply the Equation of time, found as in* (b): *the* result *is apparent time at ship, and also the sun's hour-angle (or time from noon) if* P.M.; *but if* A.M. *(or more than* 12^h*)* subtract apparent time *from* 24^h, *the* remainder *is sun's hour-angle, or time from noon required* (see Exs. 1 and 2 to 3°).

6°. **To find the True Altitude.**—*Correct the observed altitude of sun's lower or upper limb for index error* (±), *dip* (—), *refraction* (—), *parallax* (+), *semidiameter* (±), *and so get the true altitude of sun's centre* (Rule LXIV, page 193).

We now proceed to give three methods which are in general use for working this problem, but whichever method is adopted the foregoing rules always form the first part of the method.

Method I.—(By Norie.)

7°. *Take out log. rising of time from noon* (Table 29, NORIE), *log. cos. declination* (Table 25, NORIE), *and log. cos. of latitude* (Table 25, NORIE).

NOTE.—In using the natural sines and cosines to six places, it will be necessary to add 1 to the index of the log. rising, because, as given in the table, it is only adapted to five places of figures.

Caution.—In the use of the table of log. rising (XXIX, NORIE), care must be taken that the correct indices are used when the minutes of the time from noon are 1, 3, 10, or 32. It is necessary to notice that the indices in the table sometimes change in the column where they could not be inserted for want of room; this may, however, be easily known by observing that the first figure of the decimal part of the log. changes from 9 to 0.

Thus the log. rising of $0^h\ 1^m\ 0^s$ is 9·97860,
but the log. rising of $0^h\ 1^m\ 5^s$ is 0·04813.

The index, as given in the table, is in the form $\frac{9}{0}$, which means that it changes from 9 to 0 somewhere in that line. Similarly, opposite 10^m, the index is in the form $\frac{1}{2}$, and the numerator 1 is the index of the log. rising of $10^m\ 0^s$, $10^m\ 5^s$, $10^m\ 10^s$, and of $10^m\ 15^s$, and changes to 2 somewhere between $10^m\ 15^s$ and $10^m\ 20^s$.

8°. *Take the sum of these and find the natural number corresponding thereto.* (Table 24, Norie.)

9°. *To the natural number just found add the natural sine of the true altitude* (Table 26, Norie); *the sum is natural cosine of meridian zenith distance, which take out of the table, and name it* North *when the observer is* North *of the sun, or when the sun bears* South; *but call zenith distance* South *when the observer is* South *of sun, or when it bears* North (see Rule LXIV, 4°, page 193).

10°. *Apply the reduced declination to the zenith distance, taking their* sum *if they are of the* same *name, but their* difference *if of* contrary *names; the result, in either case, is the latitude of the* same *name as the* greater (Rule LXIV, 5°, page 193).

Note.—The foregoing Method (Method I) is only convenient when the computer is provided with a table of natural sines and cosines, as well as a table of log. versed sines, or the logarithmic value of 2 sine² ½ *t*.

199. We may also compute directly the reduction of the observed altitude to the meridian altitude by the following:—

Method II.

1°. Add together the following logarithms:—

Constant log. 5·615455; (*this is the log. of* $\frac{2}{\sin 1''}$.)*

Log. cosine of latitude by account (Table 25, Norie).

Log. cosine of declination (Table 25, Norie).

Log. cosecant of meridian zenith distance as deduced from latitude by D.R. and declination (Table 25, Norie).

The log. of time from noon; (this is twice *the log.* sine *of* half *the* hour-angle). (Table 31, Norie, and 69, Raper.)

The sum of these logs. (rejecting tens *from the index), will be the log. of the* reduction *in seconds* (″). (Table 24, Norie.)

The zenith distance from latitude by D.R. is found as follows:—When the *latitude* and *declination* are both of the *same* name, take their *difference;* when *latitude* and *declination* have *different* names, take their *sum:* the result in either case will be zenith distance by D.R.

2°. Add *the reduction to the true altitude: the result is the* meridian altitude.†

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* Some prefer to use the constant log. 0·301030 (this is log. of 2) instead of that given above, viz., 5·615455, the sum of logs. (rejecting tens from index), will be log. sine of reduction in minutes (′) and seconds (″). (Table 66, Raper, or Table 25, Norie.) If we omit the constant altogether the sum of the other four logs. is the log. sine of half the reduction, in minutes (′) and seconds (″), which must be multiplied by 2 to get the reduction.

† This is only an approximate meridian altitude, in strictness a second reduction should be computed.

3°. **To find the Latitude.**—*Having the meridian altitude* subtract *it from* 90°, *the* remainder *is the* meridian zenith distance, which must be named of an opposite name to the bearing, that is

If bearing is North *the zenith distance is* S.
If bearing is South *the zenith distance is* N.

4°. *Below the zenith distance place the reduced declination; then if* zen. dist. *and* decl. *are of* same name, add; *but if of* different names, *take the* difference: *the* result *is the* latitude, *of the* same name *as the* greater.

NOTE.—This Methed (Method II) does not approximate so rapidly as the preceding (Method I), but the objection is of little weight when the observations are very near the meridian. On the other hand, it has the great advantage of not requiring the use of the Table of Natural Sines.

Method III.—(By Towson's Ex-Meridian Tables.)*

1°. *Enter* Table I (TOWSON) *under nearest declination and find nearest hour-angle, against which stands Augmentation I, which* add *to declination, at the same time take out corresponding index number in the margin.*

2°. *Enter* Table II *under true altitude and opposite index number, find Augmentation II, which* add *to true altitude, and thence find latitude as in meridian altitude.*

EXAMPLES.

EX. 1. 1887, January 2nd, P.M. at ship, latitude by account 52° 6′ S., longitude 71° 23′ W., observed altitude sun's L.L. North of observer 60° 20′ 30″, index correction + 2′ 58″, height of eye 20 feet, time by watch January $2^d\ 0^h\ 48^m\ 22^s$, which was found to be $29^m\ 16^s$ *fast* on apparent time at ship, difference of longitude 32·4 miles to West: required the latitude by reduction to meridian.

Time by watch, Jan.	$2^d\ 0^h 48^m 22^s$
Watch *fast*	— 0 29 16
	2 0 19 6
Diff. long. $\frac{32'4 \times 4}{60}$	— 2 10
Time from noon, Jan.	2 0 16 56
Obs. alt. ⊙'s L.L.	60° 20′ 30″
Index correction	+ 2 58
	60 23 28
Dip for 20 feet	— 4 17
	60 19 11
Correction of alt.	— 0 28
	60 18 43
Semidiameter	+ 16 18
True altitude	60 35 1

App. time at ship, Jan.	$2^d\ 0^h 16^m 56^s$
Long. in time	+ 4 45 32
Green. date (A.T.), Jan.	2 5 2 28
H. diff., Jan. 2nd, noon	13″·55
Greenwich date $5^h\ 2^m$, or	× 5
	6,0)6,7·75
Correction	— 1′ 7″·8
Decl., page I, N.A.	
Jan. 2nd, noon	22° 55′ 26″ S. *decr.*
Correction	— 1 8
Red. decl.	22 54 18 S.

By *Raper:* Index corr. + 2′ 58″, dip — 4′ 20″, refr. — 0′ 33″, par. + 4″, semid. + 16′ 18″, true alt. 60° 34′ 57″.

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* At the Liverpool Local Marine Board Examinations the candidate is expected to solve this problem by means of TOWSON's Ex-Meridian Tables.

Method I.

Time from noon	$16^m 56^s$	rising*	3·435880
Latitude	52° 6′	cos.	9·788370
Declination	22 54	cos.	9·964347
	1544	nat. no.	3·188597
			1544
T. alt.	60° 35′ 1″	nat. sine	871073
Z. dist.	29 14 9 S.	nat. cos.	872617
Decl.	22 54 18 S.	(next greater)	638
Lat.	52 8 27 S.		239)2100(9″

* The index of log. rising is *increased* by 1. See Note to 7°, page 267.

By *Raper:* True alt. 60° 34′ 57″, red. + 10′ 53″, mer. alt. 60° 45′ 50″, latitude 52° 8′ 28″ S.

Method II.

Constant log.			5·61546
Lat. by D.R.	52° 6′ S.	cos.	9·78837
Declination	22 54 S.	cos.	9·96435
Mer. zen. dist.	29 12	cosec.	0·31171
Time from noon	$16^m 56^s$	log.	7·13486
	6,0)65,3	log.	2·81475
Reduction	+ 10′ 53″		
True altitude	60 35 1		
Meridian alt.	60 45 54		
	90		
Zenith distance	29 14 6 S.		
Declination	22 54 18 S.		
Latitude	52 8 24 S.		

Omitting const., 5·61546, the sum of logs. is log. 7·19929, and gives in Table (RAPER, 66, and NORIE, 25) half reduction 5′ 27″, which multiplied by 2 gives Red. + 10′ 54″. See note, p. 268.

By *Raper:* Lat. 52° 8′ 27″ S.

Method III.—By Towson's Ex-Meridian Tables.

⊙'s red. declination	22° 54′ 18″ S.
Aug. Table 1, Index 30	+ 3 21
Augmented declination	22 57 39 S.

This is the method required of Candidates at Liverpool.

True altitude	60° 35′ 1″ S.
Aug. Table 2, Index 30	+ 14 4
	60 49 5
Meridian zen. dist.	29 10 55 S.
Declination	22 57 39 S.
Latitude	52 8 34 S.

Ex. 2. 1887, February 6th, A.M. at ship, lat. acct. 51° 58′ N., long. 105° 41′ W., obs. alt. sun's L.L. South of observer 22° 10′ 30″, index corr. + 56″, height of eye 22 feet, time by chronometer Feb. 6^d 7^h 16^m 32^s, which was *fast* on Greenwich mean time 22^m 12^s: required the latitude by reduction to the meridian.

Time by chron.,	Feb.	6^d	7^h	16^m	32^s
Chron. *fast*		—		22	12
Green. date (M.T.),	Feb.	6	6	54	20
Long. in time		—	7	2	44
Mean time at Green.,	Feb.	5	23	51	36
Equation of time		—		14	20
App. time at ship,	Feb.	5	23	37	16
Subtract from			24	0	0
Time from noon				22	44

Obs. alt. sun's L.L.	22° 10′ 30″
Index corr.	+ 56
	22 11 26
Dip 22 feet	— 4 30
	22 6 56
Corr. alt.	— 2 11
	22 4 45
Semidiameter	+ 16 15
True altitude	22 21 0

By *Raper:* Index corr. + 56″, dip — 4′ 30″, refr. — 2′ 23″, par. + 8″, semid. + 16′ 15″, true alt. 22° 20′ 56″.

Long. in time	105° 41′ W.
	4
	6,0)42,2 44
	7 2 44

"Var. 1^h" of Eq. T.

Feb. 6th, at noon	0^s·157
Green. time 6^h 54^m	6·9
	1413
	942
Correction	1·0833

Eq. T., page II, N.A.

Feb. 6th, at noon	14^m 18^s·46 *incr.*
Corr. for 6^h 54^m	+ 1·08
Red. Eq. time	14 19·54

(*Subt.* from M.T.)

Decl., page II, N.A.

Feb. 6th, at noon	15° 37′ 4″ S., *decr.*
Corr. for $6^h\ 54^m$	— 5 19
Red. decl.	15 31 45 S.

"Var. 1^h" of Decl.

Feb. 6th, at noon	46″·22
Green. time $6^h\ 54^m$	6·9
	41598
	27732
	6,0)31,8·918
Correction	5 18·9
or,	5′ 19″

Method I.

Time from noon	$22^m 44^s$	rising	3·691630
Latitude	51° 58′	cos.	9·789665
Declination	15 32	cos.	9·983840
		2918 nat. no.	3·465135
			2918
True alt.	22° 21′ 0″	nat. sine	380263
Zen. dist.	67 28 9 N.	nat. cos.	383181
Decl.	15 31 45 S.	(next greater)	221
Latitude	51 56 24 N.		448)4000(9″

By *Raper:* True alt. 22° 20′ 56″, Red. + 10′ 51″ = Mer. alt. 22° 31′ 47″ and Lat. 51° 56′ 28″ N.

Method II.

Constant log.			5·615455
Latitude	51° 58′ N.	cos.	9·789665
Declination	15 32 S.	cos.	9·983840
Mer. zen. dist.	67 30	cosec.	0·034385
T. from noon	$22^m 44^s$	log.	7·390540
	6,0)65,1	log.	2·813885
Reduction	+ 10′ 51″		
True altitude	22 21 0		
Mer. alt.	22 31 51		
Mer. zen. dist.	67 28 9 N.		
Declination	15 31 45 S.		
Latitude	51 56 24 N.		

Method III.—By Towson's Ex-Meridian Tables.

☉'s red. declination	15° 31′ 45″ S.
Aug. Table 1, Index 57	+ 4 23
Augmented declination	15 36 8 S.

True altitude	22° 21′ 0″
Aug. Table 2, Index 57	+ 6 35
	22 27 35
Meridian zenith distance	67 32 25 N.
Augmented declination	15 36 8 S.
Latitude	51 56 17 N.

Ex. 3. 1887, Sept. 23rd, P.M. at ship, lat. acct. 51° 2′ N., long. 41° 13′ E., obs. alt. sun's L.L. South of observer 38° 44′ 20″, index corr. + 1′ 8″, height of eye 21 feet, when a chronometer showed Sept. $22^d\ 21^h\ 24^m\ 37^s$, which was $6^m\ 38^s$ *fast* on Greenwich mean time: required the latitude.

Time by chronometer	Sept. $22^d\ 21^h 24^m 37^s$
Chronometer *fast*	— 6 38
Green. date (M.T.)	Sept. 22^d 21 17 59
Long. in time	+ 2 44 52
App. time at Green.	Sept. 23^d 0 2 51
Equation of time	+ 7 34
App. time at ship	Sept. 23^d 0 10 25
Time from noon is	10 25

Green. date (M.T.)	Sept. $22^d\ 21^h 18^m 0^s$
Subtract from	24 0 0
Time *before* noon	Sept. 23^d 2 42 0

Long. in time.

41° 13′ E.
4
6,0)16,4 52
2 44 52

Obs. alt. sun's L.L.	38°44′ 20″
Index correction	+ 1 8
	38 45 28
Dip	— 4 23
	38 41 5
Corr, of alt.	— 1 4
	38 40 1
Semidiameter	+ 15 59
True altitude	38 56 0

By *Raper:* Index corr. + 1′ 8″, dip — 4′ 25″, refr. — 1′ 13″, par. + 7″, semid. + 15′ 59″, True alt. 38° 55′ 56″.

"Var. 1^h" of Eq. T.

Sept. 23rd	0^s·866
Time *before* noon 23^d	2·7
	6062
	1732
Corr.	2·3382

Eq. T., page II, N.A.

Sept. 23rd	7^m36^s·11 *incr.*
Corr. for $2^h\ 7^m$	— 2·34
Red. Eq. time	7 33·77

(*Add* to M.T.)

Decl., page II, N.A.

Sept. 23rd, at noon	0° 3′ 1″ S. *incr.*
Corr. for $2^h\ 42^m$	2 38
Red. decl.	0 0 23 S.

"Var. 1^h."

Sept. 23rd	58″·49
Time *before* noon	2·7
	6,0)15,7·923
Corr.	2 37·9
	or 2′ 38″

Method I.

Time from noon	10^m25^s	rising	3·01399
Latitude	51° 2′	cos.	9·798560
Declination	0 0	cos.	0·000000
	649	nat. no.	2·812550
		nat. no.	649
True altitude	38° 56′	nat. sine	628416
Mer. zen. dist.	51° 1′ 8″ N.	nat. cos.	629065
Declination	0 0 23 S.		
Latitude	51 0 45 N.		

In taking out log. rising for $10^m\ 25^s$, it will be noticed that the index given at the beginning of the line is $\frac{1}{2}$, meaning that the index at the commencement of the line is 1, but that it changes somewhere along the line, which may easily be known by observing that when the first figure of the decimal part of the log. changes from 9 to 0, the index changes from 1 to 2.

Method II.

Constant log.			5·615455
Latitude acct.	51° 2′ N.	cos.	9·798560
Declination	0 0	cos.	0·000000
Zen. dist. by D.R.	51 2	cosec.	0·109293
Time from noon	10^m25^s	log.	6·712960
	6,0)17,2	log.	2·236268
Reduction	+ 2′ 52″		
True altitude	38 56 0		
Meridian alt.	38 58 52		
Mer. zen. dist.	51 1 8 N.		
Declination	0 0 23 S.		
Latitude	51 0 45 N.		

Omitting const. log. the sum of the other logs. is 6·620813, which taken out of log. sins. in Table for small arcs we get half red. + 1′26, which multiplied by 2 gives Red. + 2′ 52″ (see foot of p. 268).

By *Raper:* True alt. 38° 55′ 56″, Latitude 51° 0′ 49″ N.

Method III.—By Towson's Ex-Meridian Tables.

☉'s red. declination	0° 0′ 23″ S.
Aug. Table 1, Index 13	+ 0
Augmented declination	0 0 23 S.

As the decl. is less than any given in the head of Table I, augmentation is alone required. In this case enter Table I, under least declination, and with given hour-angle find corresponding Index number; with this and the altitude, augmentation II is determined as usual.

True altitude (*Noris*)	38° 56′ 0″
Aug. Table 2, Index 13	+ 2 47
Augmented altitude	38 58 47
Zenith distance	51 1 13 N.
Augmented declination	0 0 23 S.
Latitude	51 0 59 N.

Ex. 4. 1887, May 5th, P.M. at ship, latitude account 5° 13′ N., longitude 61° E., observed altitude sun's L.L. 78° 41′ N., eye 17 feet, time by watch $5^h\ 1^m\ 7^s$, which had been found *fast* on app. time at ship $4^h\ 50^m\ 57^s$, difference of longitude made since 20½ miles West.

App. time at ship, May $5^d\ 0^h\ 8^m 48^s$ Green. date, app. time, May $4^d\ 20^h\ 4^m\ 48^s$.

Time from noon is 8 48

Hourly diff., 5th noon, $42''\cdot80 \times$ Green. time $3^h\cdot92 = 167''\cdot7760 \div 60 = 2'\ 48''$, decl. noon 5th, 16° 14′ 25″ N. — 2′ 48″ = red. decl. 16° 11′ 37″ N.

By *Norie*: True altitude 78° 52′ 47″. By *Raper*: True altitude 78° 52′ 39″.

Method I.

Time from noon	$8^m 48^s$	rising	2·867510
Latitude acct.	5° 13′	cos.	9·998197
Declination	16 12	cos.	9·982404
	705	log.	2·848111
		nat. no.	705
True altitude	78° 52′ 47″	nat. sine	981227
M. Z. dist.	10 54 31 S.	nat. cos.	981932
Declination	16 11 37 N.		
Latitude	5 17 6 N.		

This example cannot be solved by means of Towson's Ex-Meridian Tables, as the altitude exceeds the limits of the Tables.

Using *Raper's* True Alt. the Lat. = 5° 16′ 59″ N.

Method II.

Constant log.			5·61546
Latitude D.R.	5° 13′ N.	cos.	9·99820
Declination	16 12 N.	cos.	9·98240
Mer. zen. dist.	10 59	cosec.	0·72005
Time from noon	$8^m 48^s$	log.	6·56649
	6,0)76,3	log.	2·88260
Reduction	+ 12′ 43″		
True altitude	78 52 47		
Meridian altitude	79 5 30		
Mer. zen. dist.	10 54 30 S.		
Declination	16 11 37 N.		
Latitude	5 17 7 N.		

EXAMPLES FOR PRACTICE.

1. 1887, January 4th, A.M. at ship, latitude by account 36° 47′ N., longitude 27° 12′ W., observed altitude sun's L.L. South of observer was 30° 12′ 10″, index correction + 4′ 19″, height of eye 28 feet, time by chronometer January $4^d\ 1^h\ 34^m\ 40^s$, which was $5^m\ 18^s$ *slow* on Greenwich mean time: required the latitude by reduction to the meridian.

2. 1887, February 28th, P.M. at ship, lat. acct. 43° 46′ N., long. 12° 31′ W., obs. alt. sun's L.L. 38° 1′ 15″ S., index corr. — 5′ 10″, height of eye 23 feet, time by chronometer Feb. $28^d\ 1^h\ 16^m$, which was $2^m\ 4^s$ *slow* on mean time at Greenwich: required the latitude by reduction to the meridian.

3. 1887, March 20th, A.M. at ship, lat. 41° 24′ S., long. 105° E., obs. alt. sun's L.L. 47° 46′ N., index corr. + 26″, eye 22 feet, time by chronometer March $19^d\ 16^h\ 48^m$, which was $2^m\ 27^s$ *fast* on mean time at Greenwich: required the latitude by reduction to meridian.

4. 1887, April 21st, A.M. at ship, lat. acct. 39° 54′ N., long. 6° 6′ E., obs. alt. sun's L.L. 61° 26′ 35″ S., index corr. + 1′, eye 18 feet, time by chronometer April $21^d\ 0^h\ 1^m\ 6^s$, which was $45^m\ 22^s$ *fast* on mean time at Greenwich: required the latitude.

5. 1887, May 29th, P.M. at ship, lat. acct. 37° 15′ S., long. 112° W., obs. alt. sun's L.L. 30° 22′ 30″ N., index corr. + 49″, eye 22 feet, time by chronometer May $29^d\ 7^h\ 41^m$, which was $5^m\ 23^s$ *fast* on Greenwich mean time: required the latitude.

6. 1887, June 19th, A.M. at ship, lat. acct. 44° 24′ N., long. 14° 5′ W., obs. alt. sun's L.L 68° 37′ 5″ South of observer, eye 18 feet, time by chronometer June $19^d\ 0^h\ 38^m\ 42^s$, which was $3^m\ 32^s$ *slow* on mean time at Greenwich: required the latitude by reduction to meridian.

7. 1887, July 16th, A.M. at ship, lat. acct. 0° 38′ S., long. 2° W., obs. alt. sun's L.L. 67° 41′ (zenith S.), eye 15 feet, time by chronometer July $15^d\ 23^h\ 59^m$, which was $9^m\ 5^s$ *slow* on mean time at Greenwich: required the latitude by reduction to the meridian.

8. 1887, August 30th, P.M. at ship, lat. acct. 41° 15′ N., long. 139° 25′ E, obs. alt. sun's L.L. 57° 20′ S., index corr. + 2′ 21″, eye 14 feet, time by chronometer Aug. $30^d\ 0^h\ 22^m\ 22^s$, which had been found to be 18^s *slow* of app. time at ship, diff. of long. made to *West* was 34′.

9. 1887, September 9th, P.M. at ship, lat. acct. 9° 20′ N., long. 178° 30′ E., obs. alt. sun's L.L. 85° 19′ (zen. N.), eye 20 feet, time by watch $11^h 59^m 40^s$, *slow* on app. time at ship $2^m 40^s$, diff. of long. made to *East* was 10½′.

10. 1887, October 11th, P.M. at ship, lat. acct. 45° 51′ N., long. 85° 3′ E., obs. alt. sun's L.L. 36° 38′ 15″ S., index corr. — 5′ 15″, eye 16 feet, time by chronometer $10^d 18^h 50^m 10^s$, which was $5^h 40^m 12^s$ *slow* on app. time, diff. of long. 33′ W.

11. 1887, November 3rd, P.M. at ship, lat. acct. 32° 16′ S., long. 109° 39′ E., obs. alt. sun's L.L. 71° 50′ N., index corr. + 32″, eye 18 feet, time by watch $2^d 22^h 22^m$, which was found 2^h *slow*, diff. of long. 28′·7 *West*.

12. 1887, December 23rd, A.M. at ship, lat. acct. 47° 22′ S., long. 27° 3′ W., obs. alt. sun's L.L. 65° 10′ 15″ N., index corr. + 45″, eye 12 feet, time by watch $11^h 29^m 42^s$, found to be $18^m 40^s$ *slow*, diff. of long. was 36′ *East*.

13. 1887, January 5th, P.M. at ship, lat. acct., 8° 50′ N., long. 130° 14′ W., obs. alt. sun's L.L. 58° 6′ 10″ S., eye 21 feet, time by watch $0^h 2^m 40^s$, found $13^m 48^s$ *slow* on app. time, diff. of long. made since 16′ *East*.

14. 1887, April 28th, A.M. at ship, lat. acct. 18° 46′ S., long. 34° 12′ W., obs. alt. sun's L.L. 56° 28′ (zen. S.), index corr. + 1′ 5″, eye 21 feet, time by watch $11^h 49^m 50^s$, found *fast* $2^m 17^s$ on app. time at ship, diff. of long. made since 17½′ *West*.

15. 1887, March 21st, A.M. at ship, lat. acct. 19° S., long. 178° 54′ E., obs. alt. sun's L.L. 70° 21′ N., index corr. — 2′ 10″, eye 16 feet, time by watch $8^m 17^s$, found *fast* on app. time at ship $26^m 11^s$, diff. of long. made since 14½′ *East*.

16. 1887, April 12th, A.M. at ship, lat. acct. 0°, long. 164° 12′ W., obs. alt. sun's L.L. 80° 30′ N., index corr. — 5′ 10″, eye 21 feet, time by watch $12^d 0^h 0^m 2^s$, *fast* on app. time at ship $10^m 51^s$, diff. of long. made to *East* 7½′.

17. 1887, December 11th, A.M. at ship, lat. acct. 62° 40′ S., long. 100° 10′ E., obs. alt. sun's L.L. 50° 0′ N., index corr. + 2′ 10″, eye 18 feet, time by watch $10^d 17^h 2^m 46^s$, which had been found to be $9^m 30^s$ *fast* on mean time at Greenwich: required lat. by reduction to meridian.

18. 1887, July 23rd, A.M. at ship, lat. acct. 68° 25′ N., long. 35° 24′ E., obs. alt. sun's L.L. 40° 58′ S., index corr. 0″, eye 17 feet, time by watch $0^h 21^m$, found *fast* on app. time at ship $1^h 4^m 12^s$, diff. of long. made since 9′·6 *East*.

19. 1887, March 11th, P.M. at ship, lat. acct. 60° 59′ S., long. 29° 11′ W., obs. alt. sun's L.L. 32° 26′ 50″ N., index corr. — 3′ 0″, eye 13 feet, time by watch March $11^d 0^h 45^m 46^s$, found to be $24^m 41^s$ *fast*, diff. of long. was 39′ W.

20. 1887, September 22nd, A.M. at ship, lat. acct. 45° 45′ S., long. 111° 42′ W., obs. alt. sun's L.L. 43° 50′ N., index corr. — 5′ 40″, eye 18 feet, time by watch $22^d 7^h 41^m 10^s$, found to be $8^h 4^m 10^s$ *fast*, diff. of long. was 13′·5 *East*.

MERIDIAN ALTITUDE OF A FIXED STAR.

RULE LXXXI.

1°. *Take from* Nautical Almanac *the star's declination.*

2°. *To the observed altitude apply the index error, as the sign attached directs.*

3°. Subtract *the dip answering to the height of eye* (Table 5, NORIE; Table 30, RAPER).

4°. Subtract *the refraction* (Table 4, NORIE; Table 31, RAPER), *and thus get the true altitude.*

5°. Subtract *the true altitude from 90°; the remainder is zenith distance.*

6°. *Mark the zenith distance* N. *or* S., *according as the observer is* North *or* South *of the star.*

7°. ***Underneath this last place the declination, and take their* sum *if they have the* same *names; but take their* difference *if they have* unlike *names: the result, in either case, will be the latitude.***

The declination of a fixed star changes so slowly that it may be taken out of the *Nautical Almanac* by *inspection*, without any practical error resulting; a Greenwich date, therefore, is clearly unnecessary.

8°. ***When the zenith distance and declination are of the* same *name, the latitude is of* that name; *when the zenith distance and declination are of* different *names, the latitude takes the name of the* greater.**

The stars are inserted in the *Nautical Almanac* in the order of their Right Ascension, from 0ʰ to 24ʰ; it will, therefore, very much facilitate the finding of the given star in the *Nautical Almanac*, to turn, in the first instance, to the three pages 289-292, *Nautical Almanac*, 1887, and seek for the given star under the head "Mean Places of Stars" for January, and thence obtain the star's Right Ascension, which find at the top of one of the pages following 310-365, *Nautical Almanac*, 1887), which will give the star, and the declination will be found opposite the day in the side column which is *nearest* the given day. The degrees (°) and minutes (′) are placed at the top of the column (as annexed), and the seconds (″) are ranged below, for the sake of economizing space in the second column below the name of the star. If the seconds exceed 60″, only take the excess of 60″, and increase the minutes (′) at the top by 1. Thus, on May 11th, 1887 (see table annexed), the declination of α Andromedæ is 28° 27′ 50″ N., and on January 1st the declination is 28° 28′ 5″ N., 64″·5 being 1′ 5″, which being added to 28° 27′, which stands at the head of the column, gives the declination 28° 28′ 5″.

Date.	α Andromedæ	
	R.A.	Decl. N.
	0ʰ 2ᵐ	28° 27′
Jan. 1	32ˢ·35	64″·5
11	32·20	63·5
21	32·06	62·2
31	31·93	60·7
&c.	&c.	&c.
May 1	32·31	49·8
11	32·56	50·1
21	32·85	50·7
&c.	&c.	&c.

It may happen that you cannot find the star in the *Nautical Almanac* under the name given in the question; in that case refer to some other Table of Stars, as Table 13, Norie, where you will find the proper names and constellations. For instance, the star Alphacca is not found under that name in the *Nautical Almanac*, but in Table 13, Norie, you will see alongside Alphacca α Corona Borealis, which name you will find in the *Nautical Almanac*, as before.

Examples.

Ex. 1. 1887, Dec. 29th, long. 140° W., the obs. mer. alt. of the star α Leonis *(Regulus)*, bearing South, was 52° 7′ 30″, index corr. — 27″, height of eye 15 feet: required the latitude.

Observed altitude of star	52° 7′ 30″ S.
Index correction	— 27
	52 7 3
Dip 15 feet	— 3 42
	52 3 21
Refraction	— 44
True altitude	52 2 37
	90 0 0
Zenith distance	37 57 23 N.
Declination (N.A., p. 337)	12 30 48 N.
Latitude	50 28 11 N.

By *Raper:* Index corr. — 27″, dip — 3′ 50″, refr. — 46″, true alt. 52° 2′ 27″, lat. 50° 28′ 21″ N.

Ex. 2. 1887, March 12th, long. 10° E., the obs. mer. alt. of the star *Pollux*, bearing North, was 71° 59′ 10″, index corr. + 1′ 15″, height of eye 18 feet: required the latitude.

Observed altitude of star	71° 59′ 10″ N.
Index correction	+ 1 15
	72 0 25
Dip 18 feet	— 4 4
	71 56 21
Refraction	— 18
True altitude	71 56 3
	90 0 0
Zenith distance	18 3 57 S.
Declination (N.A., p. 333)	28 17 47 N.
Latitude	10 13 50 N.

By *Raper:* Index corr. + 1′ 15″, dip — 4′ 10″, refr. — 19″, true alt. 71° 55′ 56″, lat. 10° 13′ 43″ N.

Ex. 3. 1887, March 11th, long. 84° W., the obs. mer. alt. of the star α Argus (*Canopus*), bearing South, was 37° 26′, index corr. + 35″, height of eye 16 feet.

Observed altitude of star	37° 26′ 0″ S.
Index correction	+ 35
	37 26 35
Dip 16 feet	— 3 50
	37 22 45
Refraction	— 1 15
True altitude	37 21 30
	90 0 0
Zenith distance	52 38 30 N.
Declination (N.A., p. 330)	52 38 30 S.
Latitude	0 0 0

By *Raper*: Index corr. + 0′ 35″, dip — 4′ 0″, refr. — 1′ 16″, true alt. 37° 21′ 19″, latitude 0° 0′ 11″ N.

Ex. 4. 1887, January 1st, long. 100° E., the obs. mer. alt. of the star α Canis Majoris (*Sirius*), bearing South, was 59° 59′ 50″, index corr. + 4′ 12″, height of eye 24 feet.

Observed altitude of star	59° 59′ 50″ S.
Index correction	+ 4 12
	60 4 2
Dip 24 feet	— 4 42
	59 59 20
Refraction	— 33
True altitude	59 58 47
	90 0 0
Zenith distance	30 1 13 N.
Declination (N.A., p. 331)	16 33 54 S.
Latitude	13 27 19 N.

By *Raper*: Index corr. + 4′ 12″, dip — 4′ 50″, refr. — 34″, true alt. 59° 58′ 38″, latitude 13° 27′ 28″ N.

EXAMPLES FOR PRACTICE.

In each of the following examples it is required to find the latitude:—

NO.	CIVIL DATE. 1887.	LONG.	STAR.	OBS. ALT.	CORR.	EYE.
1.	Nov. 7th,	90° W.	α Andromedæ	75° 10′ 30″ S.	+ 0′ 27″	25 ft.
2.	Jan. 1st,	27 W.	α Aurigæ (*Capella*).	54 0 15 N.	— 1 45	18
3.	Aug. 19th,	84 E.	α Lyræ (*Vega*)	50 0 20 N.	0 0	22
4.	Dec. 22nd,	82 E.	α Persei	51 51 45 N.	+ 0 40	26
5.	April 11th,	142 W.	α Virginas (*Spica*)............	63 14 30 S.	+ 3 47	22
6.	June 10th,	151 E.	α Eridani (*Achernar*)	40 10 25 S.	+ 0 55	24
7.	Dec. 27th,	91 W.	(*Algenib*)	78 16 45 S.	— 0 25	24
8.	Nov. 30th,	24 W.	α Arietis	68 23 0 N.	— 1 38	28
9.	Feb. 2nd,	76 E.	α Tauri (*Aldebaran*)	29 52 10 N.	+ 5 20	15
10.	June 1st,	97 E.	α^1 Crucis	75 10 30 S.	— 1 40	14
11.	May 22nd,	178 W.	α Hydræ....................	30 28 53 S.	— 7 38	11
12.	July 17th,	29 E.	α Cygni	20 13 50 N.	0 0	18
13.	Oct. 17th,	165 E.	α Aquilæ (*Altair*)	60 49 10 N.	+ 0 55	17
14.	March 2nd,	154 W.	α Canis Majoris (*Sirius*)	58 58 50 N.	+ 1 10	20
15.	April 3rd,	111 E.	α Bootis (*Arcturus*)	79 49 40 S.	— 2 5	25
16.	Aug. 7th,	40 W.	α Scorpii (*Antares*)	68 49 30 S.	— 1 54	21
17.	May 1st,	8 E.	α^2 Centauri	10 2 50 S.	— 0 45	20
18.	Oct. 29th,	5 W.	α Piscis Australis (*Fomalhaut*)..	70 6 0 N.	+ 0 55	12

QUADRANT AND SEXTANT.

200. The Quadrant and Sextant[*] are reflecting astronomical instruments for measuring angles, and are the instruments chiefly in use for taking the observations required for the solution of a number of the most useful problems in navigation, such as to find the time, the latitude and longitude of a place. The **Quadrant** contains an arc of 45° in real extent, and measures a few degrees more than 90°;[†] it is usually of wood, and the graduated arc, which is ivory, reads to minutes, and sometimes to 30″. The **Sextant** is constructed on the same principles as the quadrant; has a graduated limb of more than 60° in real extent; and furnishes the means of measuring the angle between two objects in whatever direction they may be placed, so that the angle does not exceed 140°. The quadrant serves for common purposes at sea; but the sextant is used when considerable precision is required, as, for instance, in taking a lunar observation.

201. The form of a sextant, as at present in common use, consists of a single frame of brass, so constructed as to combine strength with lightness; and in others a double frame connected by pillars (see Fig., page 278). The graduated arc, inlaid in the brass, is usually of silver, sometimes of gold, or platinum. The explanation of the parts of a sextant, and of the adjustments of that instrument, will answer for the quadrant, since the parts and appendages are common to both.

202. The flat surface of the sextant is called the *plane of the sextant;* the circular part B C is the arc or limb, which is graduated from right to left from the zero point 0° to about 140°, and each degree in the best instruments is again sub-divided into six equal parts of 10′ each, while the vernier *g*, used in estimating the sub-divisions of the arc, shows 10″. The divisions are also continued a short distance in the opposite direction on the other side of zero (O), towards C, forming what is termed the *arc of excess*, for the purpose of determining the index error in the manner that will be subsequently explained. The microscope M, and its reflector *r*, secured at the point *d* by a movable arm *d r* to the index bar A E, may be adjusted to read off the divisions on the graduated limb and the vernier *g*. A E is the radius, or index bar, movable along the arc and round a centre, and having a dividing scale (called the *vernier*) close to the arc, by which the sub-divisions of the arc are read off. The index bar is secured to the arc B C by the intervention of a mill-headed clamp screw *s* at its back, which must be loosened when the index has to be moved any considerable distance, and when the contact nearly has been made by hand, the screw is again to be fixed, and a tangent screw *s′* enables the index bar and the vernier* upon it to be moved by a small quantity along the limb, so as to render the contact of the objects observed more perfect than could be effected by moving the index solely by hand; the other extremity of the index bar has a silvered glass or reflector, I, fixed perpendicular to the plane of the instrument, with its face parallel to the length of the index bar, and directly over the centre; another glass, *b*, is fixed perpendicular to the plane of the instrument frame H, and facing the index-glass, the lower half only is silvered (being a reflector), and the upper transparent; it is usually provided with screws, by which its position with respect to the plane of the sextant may be rectified; the plane of this glass, usually termed the horizon-glass, is made parallel to the plane of index-glass I, when the vernier *g* is adjusted to zero on the divided arc B C, or if not so made, the want of parallelism constitutes what is termed the index error of the instrument. The telescope *t* is carried by a ring fastened to a stem E, which can be raised or lowered by a mill-headed screw *s″* at the back of the frame, for the purpose of so placing the field of the telescope that it may be bisected by the line on the horizon-glass, separating the silvered from the unsilvered part, whereby the brightness of the reflected object and that seen by direct vision may be made equal, and the quality of the observations improved; the ring and its elevating apparatus are technically known as an "up-and-down piece." It is usual to supply a direct and inverting telescope, of which the latter is to

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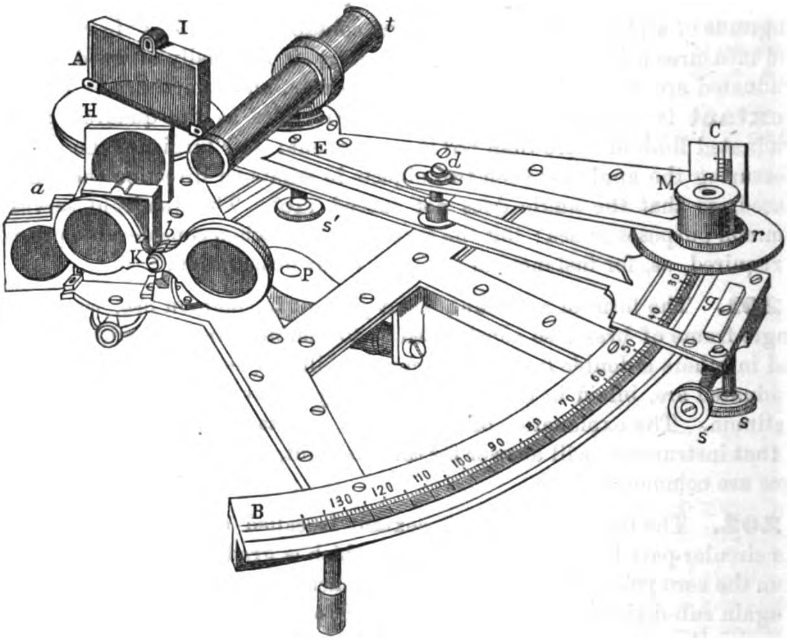
[*] The first *inventor* of the sextant (or quadrant) was NEWTON, among whose papers a description of such an instrument was found after his death, not, however, until after its re-invention by THOMAS GODFRAY, of Philadelphia, in 1730, and perhaps by HADLEY in 1731.

[†] This depends on the properties of light, which we cannot consider here. The principle of the sextant is this: the angle between the first and last direction of a ray which has suffered two reflections in one plane is equal to twice the inclination of the reflecting surfaces to each other.

Fig. 61.



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* VERNIER—so called after its inventor, PETER VERNIER, of France, who lived about 1630. By some it is called a *nonius* after the Portugese, NUNEZ or NONIUS; but the invention of the latter (who died in 1577) was quite different.

be preferred, as possessing greater magnifying power, and thus showing a better contact of the images of the objects. Two wires parallel to each other, and to the plane of the instrument, are placed in the inverting telescope, within which limit the observation should be made. In the quadrant the telescope is omitted, and the eye is applied to a small circular orifice in a piece of brass, placed in the same position as the telescope in the drawing.

Dark glasses of different colours and shades are a necessary accompaniment to the sextant to enable the sun to be observed, and they are usually attached to a hinged joint at K. Four of these glasses or shades are placed at *a*, between the index and horizon-glasses, so as to admit of one or more of them being interposed between the index and horizon-glass, to moderate the light of any brilliant object seen by reflection. Three more such glasses, sometimes called back shades, are placed behind the horizon-glass at K, any one or more of which can also be turned down to moderate the intensity of the light before meeting the eye when observing a bright object, such as the sun. There is also a dark glass which can be placed at the eye-end, *t*, of the telescope, which method is preferable to the other, as no error in this is liable to be introduced in the passage of the rays from the index to the horizon-glass.*

When observing, the instrument is to be held with one hand by the handle P placed at the back of the frame, while the other hand moves the index.

203. Reading off the Angle.—The following brief directions for reading off will be more readily understood by the learner, if he place a sextant before him for reference and examination.

It will be seen that the arc (limb) is divided into degrees and parts of a degree, from 0° (zero) to about 140°; every 10th degree is numbered from 0° to 140°; the space between every 10° is divided into 10 equal parts by straight lines; consequently every part is 1°; every fifth line is made a little longer than the others, to represent every fifth degree; and (in the best instruments) every degree is sub-divided into six equal parts by lines shorter than those which represent the degrees; those short lines divide every degree into sixths of a degree, or 10′, every third line of these short ones being made a little longer to denote 30′. On any part of the arc, therefore, the first short stroke is 10′, the second is 20′, the third is 30′, the fourth is 40′, and the fifth is 50′. We will suppose it is an instrument of this kind before the learner. The *index*, up to which an arc is read off, is a line cut in a plate at the end of the movable radius, and is generally distinguished from the other lines on the plate by a diamond-shaped mark, resembling a spear head, and sometimes by O. Supposing this index to stand exactly at any of the long lines on the arc, that is, so that the two lines are in the same direction; in such a case the reading off is easily known, for it must be a certain number of divisions, of which the value is seen at once, the reading being degrees and *no minutes;* it may be 10°, 12°, 20°, 30°, &c.—any number: but if the index exactly coincides with a short stroke in the arc, on such a case the reading off must be a certain number of divisions and sub-divisions. Thus, if it coincide, for example, with the second line to the left of 40°, then the reading off will be 40° 20′, or if it coincide with the fifth stroke to the left of 30°, the reading will be 30° 50′, since each line on the arc represents 10′.

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* With respect to the dark glasses, when it is possible (as in observing altitudes of the sun in the mercurial horizon, &c.) to make the observation with a single dark glass on the eye-end of the telescope, without using any shade, this should always be done, for the error of this dark glass does not affect the contact at all, and the distortion caused by it is not magnified, whereas any fault in the dark shade between the index and horizon-glasses produces actual error in the observation, and the distortion is magnified subsequently by the telescope.

But suppose the index not to stand exactly at any line whatever on the arc, but somewhere between two, as in the above example, between the second and third line from 40°, suppose it appeared to be about half-way between the second and third lines (the learner may place it in that position). But as this is a rough and imperfect way of estimating the additional minutes and seconds beyond the second division from 40°, the exact value of this small space is known by means of a few divisions on the index plate to the left of the index, and called the **Vernier.** These divisions are made less than the arc divisions, so that the line on the plate immediately to the left of the index is somewhat nearer to the corresponding one on the arc than the small space to be determined. It is nearer thereto, as is manifest by difference of a division on the arc and one on the index plate. In like manner the second line, reckoning from the index, must be nearer to the corresponding line by two differences, the third by three, and so on. At length, therefore, there must be a coincidence of two lines, or nearly so; that is, they must appear to an eye placed directly over them to lie in the same direction, or nearly so. And since, upon the whole, the lines on the vernier have approached those upon the arc through the small part the index is in advance of 20′, this excess must be equal to as many times the difference of two divisions, as there are lines, reckoning from the index, before this coincidence takes place. Hence, if we know the value of a difference, we shall know the value of the small arc to be measured.

This difference is known as follows:—By examining the arc of the sextant before us, it will be seen that 60 divisions of the vernier just cover or coincide with 59 divisions on the arc, or the difference between a division on the arc and one on the vernier is $\frac{1}{60}$ of a division of the arc; if, therefore, a division on the arc is 10′, the difference will be $\frac{1}{60}$ of 10′, or 10″. Every sixth division of the vernier being distinguished by a figure denoting minutes, and the interval between each of these figures is divided into six parts of 10″ each.

Hence, to **read off on a Sextant,** we proceed thus:—First examine the divisions and sub-divisions on the arc, up to the line which stands before the index. We then move the microscope on the vernier and examine the numbered lines. If any one of these coincides in direction with the opposite one on the arc, the reading off to be added will be so many minutes; if not, we observe between which numbered lines the coincidence actually takes place, and then reckon the preceding minutes as numbered, and afterwards the sub-divisions of the vernier, as so many minutes or seconds. Let us now suppose the index to stand between the second and third divisions from 40°. In reading off, first 40° 20′ is noted on the arc, and then running the microscope farther on the arc, it is observed that a line on the vernier and an arc line are in the same direction, between the lines on the vernier marked 5 and 6. The farther reading off is therefore 5′ and some seconds. On examining the interval between 5 and 6, which is divided into six equal parts, the fourth line to the left of 5 is found to be in the same direction with the opposite one on the arc. The remaining reading off is therefore 40″. Hence the whole reading off is 40° 25′ 40″.

The sextant supposed under examination is marked to read off to the nearest 10″; some instruments are graduated to 15″ or 30″, &c., but the same method of reading off is to be followed as pointed out above.

Take a sextant cut to 15″, then every degree is sub-divided into four equal parts by lines shorter than those which represent the degrees; these short strokes divide every degree into fourths of a degree, or 15′: then, on any part of the arc the first short stroke is 15′, the second 30′, and the third 45′. On the vernier the short strokes from minute to minute are each 15″. If O on the vernier is made to exactly coincide with a large stroke on the arc, the reading is degrees and *no minutes;* but if O on the vernier coincides with a short stroke, then the reading is so many divisions and sub-divisions: thus, for example, if it coincides with the third short stroke to the left of 30°, the reading is 30° 45′, since each short stroke to the left of 30° represents 15′. Again, suppose O on the vernier to stand somewhere between the first and second strokes to the left of 36°, in the first place the reading would be 36° 15′, but it must be something more, because the vernier indicates minutes between 15′ and 30′. Next look along the vernier and see which stroke on it coincides with any stroke on the arc of the sextant: let us say it is the second short stroke to the left of tenth minute stroke, that is, 10′ 30″, then the reading will be 36° 15′, and 10′ 30″ to add to it, making 36° 25′ 30″, and so on for any other indication.

Once more let us suppose the sextant to be graduated to 20′, then on any part of the arc the first short stroke is 20′, and the second 40′. If O on the vernier exactly coincides with a long mark on the arc, the reading must be a certain number of divisions, that is, degrees and *no minutes;* but if O on the vernier coincides with any short stroke or sub-division to the left of division, the reading is evidently degrees and minutes (twenties); then suppose it stands at the second short stroke to the left of 32°, the reading is 32° 40′.

Lastly, suppose O on the vernier to stand somewhere between the first and second short strokes to the left of 43°, in the first place the reading will be 43° 20′. Next look along the vernier and see which stroke on it coincides with any stroke on the arc of the sextant: let us suppose it is the second short stroke after the twelfth *long* stroke, then the reading will be 43° 20′, and 12′ 40″ to add to it, making 43° 32′ 40″.

204. To read off on the arc of excess.—As has been observed before, the graduation of the arc of the sextant is usually continued to the right of O, or zero, in which case we have to read off an arc divided from left to right by means of an index which is divided from right to left; this, however, is easily done if we remember that the line on the vernier marked 10′ must be considered as the commencement of the divisions, 9′ must be considered as 1′, 8′ as 2′, 7′ as 3′, &c.; or else take the difference between the minutes and seconds denoted by the vernier and 10′; thus, if the coincidence of lines on the arc and vernier is at 7′ 20″, we must read this as 2′ 40″; if at 5′ 40″ we must read this as 4′ 20″, and so on. Similarly, for a sextant cut to 15′, if O on the vernier stands between the second and third strokes to the right of O on the arc, and the seventh minute stroke of the vernier coincides with a stroke on the arc, then the reading of the arc of excess, that is *off*, will be 38′, since the seventh stroke is eight when reckoned from the left of the vernier.

The preceding remarks relate to the true *Quadrant* and *Sextant*, but instruments of the first kind are now not unfrequently graduated on the limb to 120°, and the second kind up to 160°; this arrangement is effected by placing the index-glass at an angle with the index-bar, and so fixing the horizon-glass that it shall be parallel with the index-glass, when 0° on the vernier coincides with 0° on the limb.

ADJUSTMENTS OF THE SEXTANT AND QUADRANT.

205. The *adjustments* of the sextant and quadrant are:—(1) *To set the index-glass and* (2) *the horizon-glass perpendicular to the plane of the instrument;* (3) *to adjust the line of collimation of the telescope*, i.e., *to set the axis of the telescope parallel to the plane of the instrument;* (4) *and to set the horizon-glass parallel with the index-glass, when* O *(zero) on the vernier coincides with* O *(zero) on the arc;* then, if the adjustments cannot be perfected, (5) *to find the index error* of the instrument:—

1st. **The index-glass, or central mirror, must be perpendicular to the plane of the instrument.**—Place the index near the middle of the *arc*. Hold the sextant with its face up, the index-glass being placed near the eye, and the limb turned from the observer. Look obliquely down the glass; then, if the part of the arc to the right, viewed by direct vision, and its image in the mirror, appear as one *continued arc of a circle*, the adjustment is perfect; if the reflection seems to *droop* from the arc itself, the glass leans *back;* if it *rises upward*, the glass leans *forward.* The position is rectified by screws at the back.

2nd. **The horizon-glass, or fixed mirror, must be perpendicular to the plane of the instrument.**—(a) *By the sea horizon.*—Set O on the index to O on the arc. Hold the instrument with its *face up;* direct the sight to the horizon-glass, give the instrument a small nodding motion; then if the horizon, as seen through the transparent part of the horizon-glass, and its image, as seen in the silvered part, appear to be in a *continued straight line*, the adjustment is perfect.

For this method of (a) testing there must be no index error, which caution is unnecessary when (b) the sun is used.

(b) *By the sun.*—The instrument being held perpendicular, look at the sun (using the shades); sweep the index-glass along the limb, and if the reflected image pass exactly over the object itself, appearing neither to the right nor left of the object, then the horizon-glass is perpendicular to the plane of the instrument; if not, turn the adjusting screw, which in some instruments is a

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mill-headed one at the back of the instrument, while in others it is a small screw behind and near the upper part of the glass itself, which can be turned by placing a capstan-pin into the hole in the head of the screw.

3rd. **The line of collimation,* or, in other words, the axis of the telescope, must be parallel to the plane of the instrument.**†—Turn the eye-piece of the telescope till two of the parallel wires in its focus appear parallel to the plane of the instrument; then select two objects, as the sun and moon, whose angular distance must not be *less* than from 100° to 120°, because an error is more easily discovered when the distance is great; bring the reflected image of the sun exactly in contact with the direct image of the moon, at the wire nearest the plane of the sextant, and fix the index; then, by altering a little the position of the instrument, make the object appear on the other wire; if the contact still remains perfect, (the images having overlapped in the middle of the field), the adjustment is perfect; if they separate, the object end of the telescope droops, *slacken* the screw *furthest* from the instrument in the ring which holds the telescope, and tighten the other; but if they overlap the reverse is the case, and the instrument must be adjusted in contrary manner.

4th. **The horizon-glass must be parallel to the index-glass.**—Set O on the index to O on the arc; screw the tube or telescope into its socket, and turn the screw at the back of the instrument till the line which separates the transparent and silvered parts of the horizon-glass appears in the middle of the tube or telescope. Hold the sextant vertically, that is, with its arc or limb downwards, and direct the sight through the tube or telescope to the horizon; then, if the reflected and true horizons do not coincide, turn the screw at the back and at the lower part of the horizon-glass till they are made to appear in the same straight line. Then will the horizon-glass be truly parallel to the index-glass.‡

206. Def.—Index Error of reflecting instruments, such as the sextant, is the difference between the zero point of the graduated limb, and where the zero point ought to be, as shown by the index when the index-glass is parallel to the horizon-glass.

5th. **To find the Index Correction.**—The two objects generally used to determine the index error are (a) the sea horizon, and (b) the sun.

(a) *By the horizon.*—Holding the instrument vertically, move the index till the horizon coincides with its image, and the distance of O on the index from O on the limb is the index error; *subtractive* when O on the index is to the *left*, and *additive* when it is to the *right* of O on the limb; but if O on the index stands exactly at O on the limb, there is *no* index error.

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* The line of collimation, *i.e.*, the path of a visual ray passing through the centre of the object-glass, and the middle point between the cross wires.

† The error caused by the imperfection of this adjustment is called the "*Error of Collimation*," and the observed angle is always too great.

‡ Some sextants, as TROUGHTON'S Pillar Sextants, are not provided with the means for making this adjustment, because it is not absolutely necessary. An allowance, called *Index Error*, being made for the want of parallelism of the two glasses when the zeroes coincide.

Ex. 1. The horizon and its image being made to coincide, the reading is 2′ *on* the arc. Then 2′ is the *Index Correction* to be *subtracted* from every angle observed.

Ex. 2. When the horizon and its image were made to coincide, the reading was 3′ 20″ *off* the arc; the index correction therefore was + 3′ 20″.

NOTE.—The reading may be on the arc proper, or on the arc of excess; it is on the latter when O on the vernier is to the right of O on the limb, and the reading is then said to be *off* the arc; when O on the vernier is to the left of O on the limb, the reading is said to be *on* the arc.

(b) *By measuring the sun's semidiameter.*—Fitting the telescope and arranging the shades so that the reflected and direct images of the sun may be viewed clearly and seen of the same brightness, measure the sun's horizontal diameter, moving the index forward on the divisions until the images of the true and reflected suns touch at the edges; read off the measure which will be *on* the arc; then cause the images to change sides, by moving the index back; take the measure again and read off; this reading will (as is generally the case) be *off* the arc; half the difference of the two readings is the index correction.

When the reading *on* the arc is the *greater*, the correction is *subtractive*; when the *lesser*, *additive*.

EXAMPLES.

Ex. 1. On the arc	— 33′ 10″		Ex. 2. On the arc	— 30′ 20″
Off	+ 30 50		Off	+ 33 30
	2)2 20			2)3 10
Index corr. *subt.*	1 10		Index corr. *add*	1 35

If both readings are *on* the arc, or both *off* the arc, half their sum is the index correction—*subtractive* when both *on*, *additive* when both *off* the arc.

Ex. 3. 1st reading on the arc	— 65′ 30″		Ex. 4. 1st reading off the arc	+ 1′ 30″
2nd " "	— 1 40		2nd " "	+ 66 50
	2)67 10			2)68 20
Index corr. *subt.*	33 35		Index corr. *add*	34 10

One-fourth of the sum of the two readings should be equal to the sun's semidiameter in the *Nautical Almanac*, for the day; but if both readings be *on* or both *off* the arc, *one-fourth* their *difference* should be the sun's semidiameter.

Thus, suppose the observations, in Example 1, to be made on September 26th, 1887; here one-fourth of the sum of the two readings is 16′ 0″, agreeing with the semidiameter as given in the *Nautical Almanac* for the given day.

This affords a test of the accuracy with which the observation has been made. But in order that the comparison may be a good criterion, we should measure the sun's *horizontal* diameter which is not sensibly affected by refraction.

Obs.—In order to obtain the index correction with the greatest precision, the mean of a number of measurements of the sun's diameter should be taken; also, the limb should be placed (by hand, before the tangent screw is used) alternately a little open and a little overlapping, so that in making the contact the tangent screw may be turned different ways.

Examples for Practice.

Ex. 1. 1887, April 17th, the reading on the arc 29′ 40″, the reading off the arc 34′ 10″: required the index correction and semidiameter.

Ex. 2. 1887, July 4th, the reading on 33′ 10″, off 29′ 50″: find index correction and semidiameter.

Ex. 3. 1887, November 13th, on 4′ 40″, off 60′ 10″: find index correction and semidiameter.

Ex. 4. 1887, July 10th, on 32′ 45″, off 34′ 30″: find index correction and semidiameter.

Ex. 5. 1887, March 21st, off 1° 10′ 0″, off 6′ 40″: find index correction and semidiameter.

Ex. 6. 1887, January 17th, on 67′ 40″, on 2′ 30″: find index correction and semidiameter.

207. The Prismatic Sextant.—In the form of instrument just described, and which is all but universally employed, the angle measureable is limited to 140°; but we may perhaps add here that Pistor and Martins, of Berlin, have, by an ingenious modification of the horizon-glass (for which they substitute a prism), produced a sextant which will measure any angle up to 180°. This instrument is called the Prismatic Sextant.

The following shows the form of Examination Paper on the adjustment of the Sextant.

EXAMINATION PAPER.

Exn. 9a.

Rotation No.

Port of

ADJUSTMENTS OF THE SEXTANT.

The applicant will answer in writing, on a sheet of paper which will be given him by the Examiner, all the following questions, numbering his answers with the numbers corresponding to the questions.

1.—What is the first adjustment of the sextant?

A.—To set the index-glass perpendicular to the plane of the sextant.

2.—How do you make that adjustment?

A.—Place the index near the middle of the arc, hold the sextant with the face upward, arc from me, and look into the index-glass so that you can see both the arc and its reflection; if they be in one line, the index-glass is perpendicular to the plane of the instrument, but if not continuous, they are brought so by the screws in the frame upon which the index-glass stands.

3.—What is the second adjustment?

A.—To set the horizon-glass perpendicular to the plane of the sextant.

4.—Describe how you make that adjustment?

A.—Place O of the vernier on O on the arc, hold the instrument obliquely, with its face upwards, and look through the telescope and the horizon-glass at the horizon; if the reflected part and the direct portions of the horizon are in one line, this adjustment is perfect, but if not, they must be brought in line by gently moving the top screw at the back of the horizon-glass.

5.—What is the third adjustment?

A.—To set the index and horizon-glasses parallel when the index is at O.

6.—How would you make the third adjustment?

A.—Place the index at O, and holding the instrument vertically, look through the telescope and horizon-glass at the horizon; if the true and reflected horizons appear in one straight line, this adjustment is perfect, but if they are not in one line, move the bottom screw at the back of the horizon-glass until they are.

7.—In the absence of a screw how would you proceed?

A.—I would find the index error.

8.—How would you find the index error by the horizon?

A.—Set the index near O, hold the instrument vertically, and, looking through the telescope and horizon-glass at the horizon, if the true and reflected parts of the horizon are not in the same straight line move the tangent screw until they form one line: the reading is the index error.

9.—How is it to be applied?

A.—To be added when the reading is off the arc, and to subtract when the reading is on the arc.

10.—Place the index at the error of   minutes to be added, clamp it, and leave it.

No answer to be written; the Examiner will see that it is correct.

This is a reading off the arc, i.e., *on the arc of excess.*

11.—The Examiner will then place the zero of the vernier on the arc, not near any of the marked divisions, and the Candidate will read it.

No answer to be written; the Examiner will see that it is correct.

In all cases the Candidate will name or otherwise point out the screws used in the various adjustments.

The above completes the examination of Second Mates.

In addition to the above Only Mates, First Mates, and Masters will be required to state in writing:—

12.—How do you find the index error by the sun?

A.—Place the index at about 30′ *on* the arc, and holding the instrument vertically, look through the telescope and the horizon-glass at the sun, two sun's will be seen; bring their upper and lower limbs in exact contact by the tangent screw, read off and mark down, then place the index at about 30 *off* the arc, or to the right of O, bring down the upper and lower limbs in contact as before, read off and mark down; half the difference of these two readings will be the index error.

13.—The readings being $\left\{ \quad \right\}$: what is the index error, and how do you apply it?

A.—To be added when the greater reading is *off* the arc, and subtracted when the greater reading is *on* the arc.

14.—What proof have you that these measurements or angles have been taken with tolerable accuracy?

A.—By adding the two readings together, and dividing the sum by 4; if the measurements are correct, the result should be nearly equal to the semidiameter for the day, as given in the *Nautical Almanac.* If they do not so agree, repeat the observations until they do.

ON THE CHART.

208. A Chart is a map or plan of a sea or coast. It is constructed for the purpose of ascertaining the position of the ship with reference to the land, and of shaping a course to any place.

209. The use to be made of the chart in each case determines the method of projection, and the particulars to be inserted. (1) The chart may be required for coasting purposes, for the use of the pilot, &c., and then only a very small portion of the surface of the globe being represented at once, no practical error results from considering that surface a plane, and a "*plane chart*" is constructed in which the different headlands, lighthouses, &c., are laid down according to their bearings. The soundings on these charts are marked with great accuracy; the rocks, banks, and shoals, the channels, with their buoys, the local currents, and circumstances connected with the tides, are also noted. (2) Again, for long sea passages the seaman requires a chart on which his course may be conveniently laid down. The track of a ship always steering the same course appears as a straight line (and can at once be drawn with a ruler) on the *Mercator's chart*. Hence the charts used in navigation are Mercator's charts. (3) When great circle sailing is practicable, and of advantage, a chart on the "*central projection*," or gnomic, exhibits the track as a straight line, and is therefore convenient.*

ON MERCATOR'S CHARTS.

(*See Norie, pages* 126-131 ; *or Raper's "Practice of Navigation," pages* 120-127, *on this subject.*

210. A chart used at sea for marking down a ship's track and for other purposes, exhibits the surface of the globe on a plane on which the meridians are drawn parallel to each other, and therefore the parts B H, C I, D K, &c. (Fig. 13, page 70), arcs of parallels of latitude, are increased and become equal to the corresponding parts of the equator U V, V W, &c. Now, in order that every point of this plane may occupy the same relative position with respect to each other that the points corresponding to them do on the surface of the globe, the distance between any points, A and O, and A and F must be increased in the same proportion as the distance F O has been increased. The true difference of latitude, A O, is thus projected on the chart into what is called the *meridional difference* of latitude, and the departure BH + CI + DK, &c., into the difference of longitude, and the representation is called a Mercator's projection (see pages 73-75, and Fig. 16). It is evidently a true representation as to *form* of every particular small track, but varies greatly as to point of *scale* in its different regions, each portion being more and more enlarged as it lies farther from the equator, and thus giving an appearance of distortion.*

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* The method lately introduced by HUGH GODFRAY, Esq., M.A., St. John's College, Cambridge, deserves special mention, as its beauty and simplicity will ultimately lead to its general adoption. A chart on the central projection, as stated above, exhibits the great circle as a straight line, and thus it is seen at once, whether the track between two places is a practicable one; hence, also, we have by inspection the point of highest latitude. An accompanying diagram then gives the different courses, and distances to be run on each, in order to keep within ¼ of a point to the great circle. This chart and diagram is fully described in the *Transactions of the Cambridge Philosophical Society*, vol. X, part II, and is published by J. D. Potter, Poultry.

(1.) In charts generally, the upper part as the spectator holds it, is the North, the lower part South, and that towards his right hand the East, that towards the left West, as on the compass card.

In a case which sometimes happens when the upper part is not the North, the North part may be known by the North part of the compass.

(2.) On Mercator's chart the parallel lines from North to South (from top to bottom) are termed *meridians*, and they are all perpendicular to the equator; the meridians on the extreme *right* and *left* are the *graduated* meridians —so called from showing the divisions for degrees and minutes. The *latitude* is measured on the graduated meridians, and also the *distance*.

(3.) The parallel lines from West to East (from left to right) are called *parallels*, and they are all parallel to the equator, the parallels at the top and bottom are *graduated* to degrees and minutes—and longitude is measured on the graduated parallels. *Distance cannot be taken from them.*

(4.) The depth of water is denoted, as also in some places the quality of the bottom. The numerals or figures in harbours, bays, channels, &c., indicate *soundings reduced to low water ordinary spring tides.* The *Roman figures* indicate the time of high water at full and change of the moon. Thus: XI hrs. 34^m F & C means that the time of high water is thirty-four minutes past eleven on days of full and new moon. The *anchors* on the chart denote anchorage. The small *arrows* show the *direction of the set of the current*, the current going with the arrow.

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* It is plain from the principles of Mercator's projection, and from the diagram (page 131) which connects the enlarged meridian with the difference of longitude, that if a ship set out on any point on the globe, and sail on the same oblique rhumb towards the pole, it can reach it only after an infinite number of revolutions round it. For from any point to the pole, the projected meridian is infinite in length, and so, therefore, is the difference of longitude due to this advance in latitude upon an oblique course. Consequently, this latitude can be reached only after the ship has circulated round the pole an infinite number of times.

These endless revolutions, however, are all performed in a finite time, the entire track of the ship being of limited extent. This, however paradoxical it may appear, is necessarily true from the principles of plane sailing, which shows that any finite advance in latitude is always connected with a finite length of track, this length being $\frac{\text{diff. lat.}}{\text{cos. course}}$.

The apparent paradox of the infinite number of revolutions about the pole being performed in a finite time, becomes explicable when we consider that, whatever be the progressive rate of the ship along its undeviating course, the times of performing the successive revolutions continually diminish as the ship approaches the pole, both the extent of circuit and the time of tracing it tending to zero, the limit actually attained at the pole itself; hence there must ultimately be an infinite number of such circuits to occupy a finite time.

When the pole is reached the direction all along preserved may still be continued, and a descending path will be described similar to that just considered, and which will conduct the ship to the opposite pole, after an infinite number of revolutions round it, as in the former case. In receding from this pole the track described will at length unite with that at first traced, the point of junction being that from which the ship originally departed. But for the strict mathematical proof of these latter circumstances the student may consult Professor DAVIES' curious and instructive papers on *Spherical Co-ordinates* in the Edinburgh Transactions, vol. XII.

(5.) Lines, called *Compasses*, similar to those on the compass card, are drawn at convenient intervals on the chart. In charts of large seas, as the Atlantic, these compasses are generally drawn so that the line from the North to the South point corresponds with the true meridian; but in coasting charts the same line generally coincides with the *correct* magnetic meridian.

The Candidate's attention is drawn to the following points in connection with charts.

A strange chart being placed before you, it should be your special care to determine, before you answer any question concerning it, or attempt to make use of it, which is the North part of the chart. In the case of British charts this may be known by the fact that there is always at least one compass the true North point of which is determined by a star or other ornament.

The Examiner will hand the Candidate a Mercator's chart, and he will be required to determine whether the chart is a "true" or "magnetic" one, and whether it is for the northern or southern, and eastern and western hemisphere.

In the first place then, remember that all charts are projected true, but the *compass* on the chart may be *true* or *correct magnetic*. When the North and South line of the compass is on a meridian, or runs in a line parallel with the meridians, and its East or West line is either on or parallel with the parallels of latitude, such a compass is a *true* compass; otherwise it is intended to be *correct magnetic*, and the variation is usually inserted within the compass. If the distance between the parallels increases upwards, *i.e.*, towards the top of the chart, it represents a part of the northern hemisphere, but if it increases downwards, it is part of the southern hemisphere. If the degrees and minutes on the graduated parallels (top and bottom of chart) increase toward the right the longitude represented thereby is East, if they increase toward the left the longitude is West. If the meridian of Greenwich (long. 0°) comes on the chart, the longitude to the right of that meridian is East, and to the left it is West.

If the meridian of 180° comes on the chart, the longitudes to the *right* of that meridian will be West, and the longitudes to the *left* of the same meridian will be East. But the West longitudes will *increase from right to left*, and the East longitudes will *increase from left to right*, as far as that meridian.

PRACTICAL EXAMINATION ON THE USE OF THE CHART.

For Only Mates, First Mates, and Masters.

The Deviation Tables given below are to be used in all the questions on the use of the Chart. It should be particularly noticed that these Tables contain the Deviation of the Compass for all directions of the ship's head by compass, whereas, in the Examination, we have to find the deviation of the compass for a given direction of the ship's head *correct magnetic*. This may easily be found by Napier's diagram *(if allowed)*; if not allowed it may be found by allowing the deviations from the table on the courses opposite to which they stand, the results will be the Correct Magnetic Courses corresponding to the Compass Courses or Ship's Head by Compass. We have thus a second Table of Deviations for Ship's Head Correct Magnetic (see Col. 3, Table B, page 291).

DEVIATION CARD—No. I.

SHIP'S HEAD WHEN BUILDING.

Ship's Head By Compass	Deviations.	Ship's Head By Compass	Deviations.
North	7° W.	South	6° E.
N. by E.	8 W.	S. by W.	14 E.
N.N.E.	9 W.	S.S.W.	23 E.
N.E. by N.	11 W.	S.W. by S.	27 E.
N.E.	13 W.	S.W.	29 E.
N.E. by E.	15 W.	S.W. by W.	28 E.
E.N.E.	18 W.	W.S.W.	26 E.
E. by N.	20 W.	W. by S.	23 E.
East	22 W.	West	19 E.
E. by S.	24 W.	W. by N.	15 E.
E.S.E.	25 W.	W.N.W.	11 E.
S.E. by E.	25 W.	N.W. by W.	7 E.
S.E.	24 W.	N.W.	3 E.
S.E. by S.	19 W.	N.W. by N.	0 E.
S.S.E.	11 W.	N.N.W.	3 W.
S. by E.	3 W.	N. by W.	5 W.

DEVIATION CARD—No. II.

SHIP'S HEAD WHEN BUILDING.

Ship's Head By Compass	Deviations.	Ship's Head By Compass	Deviations.
North	10 E.	South	10 W.
N. by E.	18 E.	S. by W.	11 W.
N.N.E.	25 E.	S.S.W.	13 W.
N.E. by N.	29 E.	S.W. by S.	15 W.
N.E.	32 E.	S.W.	17 W.
N.E. by E.	33 E.	S.W. by W.	19 W.
E.N.E.	31 E.	W.S.W.	21 W.
E. by N.	28½ E.	W. by S.	23 W.
East	24 E.	West	23 W.
E. by S.	18 E.	W. by N.	22 W.
E.S.E.	10 E.	W.N.W.	20 W.
S.E. by E.	5 E.	N.W. by W.	18 W.
S.S.E.	1 W.	N.W.	15 W.
S.E. by S.	4 W.	N.W. by N.	10 W.
S.S.E.	6 W.	N.N.W.	3 W.
S. by E.	8 W.	N. by W.	3½ E.

Given a correct magnetic course by the chart between two points of land, to find the course that must be steered by compass.

Having found ship's head correct magnetic (see Col. 3, Table B) *by applying deviation to ship's head by compass* (Rule XXXVI, page 104).

Find the deviation corresponding to the given correct magnetic course in column 3 of Table of Deviations (see Table B, below), and apply the deviation to the correct magnetic course the *reverse* way to that given in Rule **XXXVI**, page 104, to find the correct magnetic course, having given the compass course; namely, apply *easterly* deviation to the **left** of the correct magnetic course and *westerly* to the **right** as in the following example.

Note.—When the correct magnetic course proposed to be made does not correspond to any of the courses in column 3 of Table of Deviations, nor near midway between them; then, if the deviation is large, the corresponding deviation may be found by proportion, as in the following:—

Ex. Correct magnetic course by chart S. 45° E.: required the course to be steered by compass (deviations as annexed Table A).

Table A.

Ship's Head by Compass.	Deviation
South	13° W.
S. by E.....	21 W.
S.S.E.	26 W.
S.E. by S...	31 W.
S.E.	37 W.

Table B.

Ship's Head by Compass. Col. 1.			Deviation Col. 2.	Ship's Head Correct Magnetic. Col. 3.
South	or	0°	13° W.	S. 13° 0′ E.
S. by E.	„	S. 11 15′ E.	21 W.	S. 32 15 E.
S.S.E.	„	S. 22 30 E.	26 W.	S. 48 30 E.
S.E. by S. ..	„	S. 33 45 E.	31 W.	S. 64 45 E.
S.E.	„	S. 45 0 E.	37 W.	S. 82 0 E.

S. 32° 15′ E., next less to 45°.
S. 48 30 E., „ greater to 45°.
Diff. 16 15 in value of a point.

Correct magnetic course = S. 45° 0′ E.
Next *less* course in column 3 = S. 32 15 E.
Diff. 12 45
12°·7

Deviation at S. 32° 15′ E. is 21° W.
S. 48 30 E. is 26 W.
Change in deviation 5

16°·2 : 5° :: 12°·7
5
16·2)63·5(4° nearly.
648

Deviation at S. 48° 30′ E. is 26 W.
Corr. for 3° 30′ *subt.* 1
Deviation at S. 45° E. 25 W.
Correct magnetic course S. 45 E.
Compass course S. 20 E.

QUESTION I.

Using Deviation Card, No. ——, find the course to steer by compass from ———— to ————; also the distance.

RULE LXXXII.

To find the Course.—*Lay a pair of parallel rulers over the points indicated by* A *and* B, *and join these points by a straight line. Then, taking care to preserve the direction of the parallels, move them to the centre of the compass, when* the **True** or **Correct Magnetic** Course is found according as the compass on the chart is a *True* or *Magnetic* compass.

If the compass on the chart is a *True* compass you must seek on the chart the variation nearest the place of the ship, and apply it

Easterly variation to the *left*.
Westerly ,, *right*.

which will give the *Correct Magnetic Course*.

Now apply the Deviation—same way as variation—viz.:—

Easterly to the *left* and *Westerly* to the *right*.

This will give the Compass Course.

If the compass is a **magnetic compass** having found the magnetic course you proceed to apply the deviation as directed above.

To find the Distance.—*Take half the distance between the two points* (A and B), *and placing one leg of the dividers on the graduated meridian at the* latitude of the point midway between the two points *measure on each side of the same, and the number of degrees between the extreme points brought into miles is the* distance required.

QUESTION II.

With the ship's head on the above compass course ——— bore by compass ———, and ——— bore ——— by same compass: find the ship's position.

RULE LXXXIII.

1°. If the compass on the chart is a **True Compass.**—*Find the* True Bearing *of* each *point by allowing*

Easterly variation to the **right**
Westerly ,, **left**

and also

Easterly deviation to the **right**
Westerly ,, **left**

but the deviation must be that due to the direction of the ship's head at the time of making the observation.

2°. If the compass on the chart is **correct magnetic.**—*Correct the compass bearings for* deviation *only (as above directed). Having found the* **true** bearings *or* correct magnetic bearings *(as the case may be) of* each *point; then from* each *point draw lines* opposite *to the* bearings, *and the* point *of* intersection *is the position of the ship.*

QUESTION III.

With the ship's head as above ——— bore by compass ———, and after continuing the same course —— miles it bore ———: find the position of the ship and her distance from ——— at the time of taking the second bearing.

RULE LXXXIV.

1°. If the compass on the chart is a **True Compass.**—*Find the true bearings of the point by allowing the deviation and variation as in* Question II.

2°. If the compass on the chart is a **Correct Magnetic Compass.**—*Find the* correct magnetic bearings *of the point by correcting the compass bearings* *for deviation only, as in* Question II. *Then, the ship's course having been set off, from the* given *point, or lighthouse, draw a line* opposite *to the first corrected bearing cutting the line* A B *in a point which call* a. *Draw another line running in an opposite direction to the second corrected bearing, which name* b. *From the spot where the first bearing crosses the course lay off the distance run, taken from the graduated meridian;* the extremity of this *distance, which name* d, *may not* reach to, *or it may* reach beyond, *the crossing spot of the second bearing, in either case draw a line* parallel *to the* first bearing, *such that it shall* pass through the extremity *of the distance* run *and* cut *the line of the second bearing; the ship's position is where the last* line *crosses the* second *bearing, thence measure the distance from the point, and take off the ship's position.*

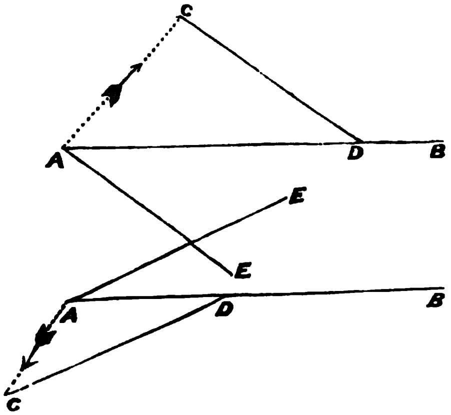
QUESTION IV.

Find the course to steer by compass from ——— to ——— (see Question I.) to counteract the effect of a current which set ———, at the at the rate of —— miles per hour, the ship making by log —— miles per hour; also, the distance the ship would then make good in ——— hours towards ———.

RULE LXXXV.

Draw a line on a chart to represent the course to be made good; from the ship's place on the chart lay off a line in the direction of the set of the current, on which mark off from the ship's place the rate of the current per hour; then take in the compasses the distance the ship sails in an hour by log, and put one foot on the last-named mark, and from the point where the other foot reaches the first line draw a line to the mark on the line representing the direction of the current. The course to be steered is represented by the line last drawn, and the parallel ruler being placed to it, and moved to the centre of the compass on the chart, will give the course of the ship; and that portion of the first line drawn, intersected by the last line drawn, will be the distance the ship will make good per hour.

Fig. 62.



On a chart, suppose A to be the place of the ship, B the point of destination; also A C the set of the current, the rate per hour being taken from the scale of miles and laid off in the direction of the line. Take the distance sailed by the ship per hour from the scale of miles, and with one foot of the dividers at C, make an arc cutting A at D. Join CD, and move the parallel ruler from CD to A, drawing AE parallel to CD; then AE will be the direction of the ship's head; and the parallel ruler being moved to the centre of the compass on the chart, will give the course of the ship on the chart; and AD will be the distance the ship will make good.

EXAMPLE I.—(True Chart—Chart used for working Sumner's.)

(I.) Using Deviation Card No. I: find the course to be steered by compass from A to B, also the distance (variation 11° E.)

Latitude A 52° 5′ N. Longitude A 176° 50′ E.

Lay an edge of a parallel ruler over the positions A and B, then move the parallel rule (strictly preserving the direction) until an edge pass through the centre of the (true) compass, then the point of the compass corresponding with the edge of the ruler shows the true course from A to B—it will be found to be S. by E.; then proceed as follows:—

True course	S. by E. =	S. 11°E. (L. of S.)
Variation		11 E., allow to *left* (L.)
Correct magnetic course		S. 22 E. (L. of S.) = S.S.E.
Deviation for S.S.E.		6 W., allow to *right* (R.)
Compass course		S. 16 E. = S. by E. ½ E.

The variation being 11° E., this allowed to the *left* makes correct magnetic course S. 22° E., or S.S.E. (Rule LXXXII). Then entering Deviation Table, Card I, we take out the deviation for S.S.E., nearest to S. 22° E. (note that deviation has to be applied as in correcting courses in Day's Work), and proceed thus:—

Compass Courses
S.S.E. = S. 22°30′ E. (L. of S.)
Deviation 11 0 W. (L.)
Correct mag. course S. 33 30 E.
which is *greater* than given correct magnetic course S. 22° E..

Next, enter Table with compass course S. by E.
S. by E. = S. 11°15′ E. (L. of S.)
Deviation 3 0 W. (L.)
Corr. mag. course S. 14 15 E.
which is *less* than given corr. mag. course S. 22° E.

It is evident that the correct mag. course S. 22° E. lies between S. 14° 15′ E. and S. 33° 30′ E., and that the required deviation will, therefore, lie between the deviations for these two last corr. mag. courses, that is the deviation lies between 3° W. and 11° W., and may be found by proportion as follows:—

Corr. mag. course S. 14°15′ E. gives Dev. 3°W.
„ S. 33 30 E. „ 11 W.
Diff. for 1 point 19 15 Change dev. 8
or, 19°·2

Given Corr. mag. course S. 22° 0′ E.
Next *less* „ S. 14 15 E.
7 45
7°·7

Then 19°·2 : 7°·7 :: 8°
8
19·2)61·6(3·2
576
400

Deviation for corr. mag. course S. 14° 15′ E. = 3°W.
Corr. for 7°·7, to be *added* + 3
Deviation for corr. mag. course S. 22° E. = 6 W.

Whence the deviation for correct magnetic course S. 22° E. is 6° W.; this must be allowed to the *right* (opposite way to that when correcting courses in Day's Work) on the correct magnetic course, making *compass* course S. 16° E., or S. by E. ½ E. Write down this compass course, and also the distance from A to B as measured in the usual way on the graduated meridian.

Answer.—Compass course S. by E. ½ E., distance 61 miles.

(II.) With the ship's head on the above-named compass course, D bore by compass N. 54° E., also, E bore S. 85° E. by the same compass: find the ship's position.

The compass on the chart being a true compass, and as in this question (II) the *bearings* are given by compass, with the ship's head on the course from A to B, as found in the previous question (I); the *compass* bearings must, therefore, be turned into *true* bearings by allowing the deviation proper to the course and the given variation; that is, the same corrections (deviation 6° W., and variation 11° E.) applied to the compass bearings of D and E (but in a contrary way to that in Question I) give their true bearings, N. 59° E. = N.E. by E. ¼ E., and S. 80° E. = E. ¾ S.; thus:—

	D.	E.
Compass bearings	N. 54° E. (R of N)	S. 85° E. (L of S)
Deviation same as Question I, allow to *left*	6 W. (L)	6 W. (L)
Correct magnetic bearings	N. 48 E. (R of N)	S. 91 E. (L of S)
Variation same as in I, allow to *right*	11 E. (R)	11 E. (R)
True bearings	N. 59 E. = N.E. by E. ¼ E.	S. 80 E. = E. ¾ S.

Having found the true bearings of the points D and E, we now proceed to lay off these bearings on the chart, thus:—

Place the parallel rules on the compass on the chart, having an edge over N.E. by E. ¼ E. and S.W. by W. ¼ W., then work the parallels (preserving the direction) till an edge lie over D; draw a line from D, trending S.W. by W. ¼ W., toward the line A B (always take care that the lines of bearing are drawn in a contrary direction), so that as the ship is somewhere on A B, the point shall bear N.E. by E. ¼ E. Again, place the parallel rules on the compass over E. ¾ S. and W. ¾ N., then move the parallels (being careful to preserve the direction) till an edge lies over E, then draw a line trending W. ¾ N. from E towards the line A B; the point where these two lines intersect is the ship's position, the latitude and longitude of which, found in the usual way, is

Answer.—Latitude 51° 35′ N.
Longitude 177 0 E.

(III). With the ship's head on the above compass course, C bore N. 85° E., and after continuing on the same course 13 miles it bore N. 39° E.: find the position of the ship and her distance from C at the second bearing.

First, the two *compass* bearings are to be turned into *true* bearings, by applying the same corrections as in II.

1st Compass bearing	N. 85° E. (R of N)	2nd Com. bear.	N. 39° E. (R of N)
Dev. same as in I, allow to *left*	6 W. (L)		6 W. (L)
Correct magnetic bearing	N. 79 E. (R of N)		N. 33 E. (R of N)
Var. same as in I, allow to *right*	11 E. (R)		11 E. (R)
1st True bearing	N. 90 E. = East.		N. 44 E. = N.E.

Place the parallel rules on the compass on the chart, over the first true bearing which lies East and West, and working the parallels (strictly preserving the direction) till an edge lies over C. Draw a line trending West from C (*i.e.*, in a contrary direction to the bearing from the ship), cutting the line A B in a point which call *a*. Again, proceed to lay off the second true bearing, N.E., by laying the parallels over N.E. and S.W. on the compass on the chart (and being careful to preserve the direction), move them to the point C, and draw another line running S.W. (*opposite* the bearing) toward the ship, and cutting the line A B in a second point, which mark *b*. Next, with a pair of dividers, take the distance sailed, 13 miles, from the graduated meridian and lay it off from *a* towards *b*, and mark the point to which the foot of the dividers extend *d*. Through *d* draw a line parallel to the line of first bearing, and where this parallel line cuts the line of second bearing is the ship's position at the time of taking the second bearing. The ship's distance from C will be found to be 17 miles, and the ship's latitude to be 51° 10½' N., and the longitude 177° 8' E.

Answer.—Latitude 51° 10½' N.
Longitude 177 8 E.
Distance 17 miles.

IV. Find the course to steer by compass from A to B (see Question I) to counteract the effect of a current which set E.N.E. (true) at the rate of 8 miles per hour, the ship making by log 14 miles per hour; also, the distance the ship would make good per hour towards B (see Rule LXXXV, page 293).

The current setting E.N.E. (true) lay an edge of the parallel rules over E.N.E. on the compass on the chart, then move the parallels (being careful to preserve the direction) until an edge lies over A (the ship's position on the chart), and from A draw a line in an E.N.E. direction. With a pair of dividers measure on the graduated meridian 8 miles, the rate of the current per hour, and measure this off on the line just drawn, and call this line A *a*, then take in the compasses the distance 14 miles (also measured on the graduated meridian) which the ship sails an hour by log, and put one foot on the last named mark (*a*) and at the point where the other foot reaches A B make a mark and call it *e*; draw a line from *e* to *a*. The course to be steered is represented by this line last drawn, and the parallel rules being placed to it, and moved to the centre of the compass on the chart, gives the true course of the ship S.S.W., westerly. Then proceed thus:—

True course S.S.W.	S. 22° 30' W. (R of S)
Variation, allow to *left*	11 0 E. (L)
Correct magnetic course	S. 11 30 W. (R) = S. by W.
Deviation, allow to *left*	8 0 (L) (see Table below.)
Compass course	S. 3 30 W. = S. ½ W., westerly

S. ½ W., westerly, is therefore the course to steer in order to make allowance for the current. The distance from *a* to *e* taken in the dividers and applied to the graduated meridian gives 10 miles, the distance made good per hour towards B.

Corr. mag. course S. 6° 0' E. gives Dev. 6° E.
„ S. 25 15 E. „ 14 E.
19 15 8
or, 19°·2

Given corr. mag. course S. 11° 30' W.
Next *less* S. 6 0 W.
5 30
5°·5

Ship's Head by Compass.	Deviation	Ship's Head Correct Magnetic.
South	6° E.	S. 6° 0' E.
S. by W...	14 E.	S. 25 15 E.
S.S.W.....	23 E.	S. 45 30 E.

19°·2 : 5°·5 :: 8°
8
19·2)44·0(2°
384
56

Deviation for corr. mag. course S. 6° 0' E. is 6° E.
Corr. for 5°·5 + 2
Deviation for corr. mag. course S. 11° 30' E. is 8 E.

EXAMPLE II.

(I.) Using Deviation Card No. I: find the course to steer by compass from A to B, also the distance. (Chart used for Sumner's work).

Lat. A 50° 25' N.	Long. A 176° 23' E.	
Lat. B 50 5 N.	Long. B 178 45 E.	Var. 29° E.

Place an edge of a parallel rule over the positions A and B, and move the parallels (strictly preserving the direction) until an edge pass through the centre of the compass, then it will be seen that the true course from A to B is E. by S. ⅛ S. The variation 29° E., allowed to the *left* because it is required to deduce a *correct magnetic* course from a *true* course, makes correct magnetic course S. 106° 21′ E. or N. 73° 39′ E. = E. by N. ½ N. Then the deviation for correct magnetic course E. by N. ½ N. is 23° W. (see Table I); this must be applied to the *right* hand, whence the compass course is found to be S. 83° 21′ E., thus:—

True course E. by S. ⅛ S. =	S. 77° 21′ E. (L. of S.)
Variation, allow to *left*	29 0 E. (L.)
Exceeds 90°	S. 106 21 E.
Subtract from	180 0
Correct magnetic course	N. 73 39 E. (R. of N.) = E. by N. ½ N.
Deviation (Table I), allow to *right*	23 0 W. (R.)
Exceeds 90°	N. 96 39 E. (R. of N.)
Subtract from	180 0
Compass course	S. 83 21 E. = E. ⅝ S.

(See Dev. Card, No. I.

Ship's Head by Compass.	Deviation	Ship's Head Correct Magnetic.
E. by N. ..	20° W.	N. 58° 45′ E.
East	22 W.	N. 68 0 E.
E. by S. ..	24 W.	N. 77 15 E.

Corr. Mag. Course.	Dev.	Cor. Mag. Course.
N. 68° 0′ E.	22° W.	N. 68° 0′ E.
N. 77 15 E.	24 W.	N. 73 39 E.
9 15	2	5 39
9°·2		or, 5°·6

9°·2 : 5°·6 :: 2°
2
9·2)11·2(1°

Dev. for N. 68° 0′ E. is 22° W.
Corr. for 5°·6 is + 1
∴ Dev. for N. 73° 39′ E. is 23 W.

(II.) With the ship's head on the above-named course, a point D bore by compass N. 17° W.; also, a point E bore N. 33° E. by the same compass: find the ship's position.

Lat. D 50° 30′ N.	Long. D 177° 56′ E.
Lat. E 50 28 N.	Long. E 178 23 E.

The compass on the chart used being a *true* compass, the compass bearings above must be reduced to the true bearings; and since the ship's head is on the same course as in Question I, therefore the same deviation and variation must be applied (but the *contrary* way) to the compass bearings in order to reduce them to true bearings. Applying these same corrections, viz., deviation 23° W., and variation 29° E., to the compass bearings of D and E, westerly deviation to the *left* and easterly variation to the *right*, gives their true bearings N. 11° W. = N. by W., and N. 39° E. = N.E. ½ N., thus:—

	D.	E.
Compass bearings	N. 17° W. (L of N)	N. 33° E. (R of N)
Deviation same as in I, allow to *left*	23 W. (L)	23 W. (L)
Correct magnetic bearing	N. 40 W. (L)	N. 10 E. (R of N)
Variation same as in I, allow to *right*	29 E. (R)	29 E. (R)
True bearings	N. 11 W. = N. by W.	N. 39 E. = N.E. ½ N.

Next, proceed to draw a line running S. by E. from D (opposite to bearing from ship), and another S.W. ½ S. from E (opposite to bearing of E from ship); the point where these two lines intersect is the ship's position; the latitude and longitude of this point is found to be latitude 50° 12′ N., and longitude 178° 2′ E.

(III.) With the ship's head as above, a point O bore by compass N. 43½° E., and after continuing on the same course 22 miles it bore N. 40° W.: find the position of the ship and the distance from O at the time of taking the second bearing.

Lat. O 50° 30′ N. Long. O 177° 15′ E.

These bearings also, being compass bearings, are to be reduced to true bearings by using the same corrections as in Question I, viz.:—Dev. 23° W., var. 29° E., but applied the contrary way to that of Question I, whence is found the true bearings of O to be N. 49½° E. = N.E. ½ E., and N. 34° W. = N.W. by N. The work is as follows:—

1st Compass bearing of O	N. 43½° E. (R of N)	2nd Com. bearing	N. 40° W. (L of N)
Dev. same as I, applied to *left*	23 W. (L)	Dev.	23 W. (L)
Correct magnetic bearing	N. 20½ E. (R of N)	Corr. mag. bearing	N. 63 W. (L of N)
Var. same as I, applied to *right*	29 E. (R)	Variation	29 E. (R)
1st True bearing	N. 49½ E. = N.E. ½ E.	2nd True bearing	N. 34 W. = N.W. *b* N.

These two bearings are to be laid off from O, cutting the points *a* and *b*. Next with a pair of dividers take 22 miles from the graduated meridian, and lay this distance from *a* towards *b*, and the point to which they extend is called *d*. Through *d* draw a line parallel to the line of first bearing, and where this parallel line cuts the line of second bearing is the ship's position at the time of taking the second bearing. The distance of the ship from O will be found to be 17¾ miles. Lat. 50° 15¾′ N., and the Long. 177° 30½′ E.

(IV.) Find the course to steer from A to B (see Question I) to counteract the effect of a current which set East (true) at the rate of 3 miles an hour, the ship making by log 40 miles in 5 hours; also the distance the ship would then make in 5 hours towards B.

From A draw a line running East, to denote the set of the current. The rate of the current being 3 miles per hour, this will give 15 miles drift in 5 hours. Take 15 miles with the dividers from the graduated meridian, and mark off this distance from A on the line representing the set of the current, and call this point *a*. Then take in the compasses the distance 40 miles, which the ship has made by log in the time (also measured on the graduated meridian), and placing one foot of the dividers on *a*, and at the point where the other foot reaches A B make a mark and call it *c*, draw a line from *a* to *c*. The course to be steered is represented by the last line drawn, and placing the edge of the parallel rules over *a c*, and working them down to the centre of the compass on the chart, gives E. by S. ½ S. (southerly) as the *true* course the ship must make good from A to B to counteract the effect of the current. Correct this course for the *variation* 29° E., as in Question I, to get the *correct magnetic course*; and enter Deviation Table, No. I, in the column "Ship's Head by Compass," and thence find the deviation corresponding to the correct magnetic course, and the result will be the course to steer.

True course E. by S. ½ S., southerly =	S. 72° E. (L of S)
Variation	29 E., *left*.
Exceeds 90°	S. 101 E. (L. of S.)
Subtract from	180
Correct magnetic course	N. 79 E. = E. by N. (R of N)
Deviation (Table I)	24 W. (R)
Exceeds 90°	N. 103 E.
Subtract from	180
Compass course	S. 77 E. = E. by S., southerly.

E. by S., southerly, is therefore the course to steer to counteract the effect of the current. The distance A *c* taken in the dividers and applied to the graduated meridian gives 55 miles as the distance made good in 5 hours towards B,

EXAMPLE III. (Chart used for working Sumner's.)

(I.) Using Deviation Card No. I: find the course to be steered by compass from A to B, also the distance. Variation 21° W.

Lat. A 51° 55′ N.	Long. A 179° 5′ E.
Lat. B 51 40 N.	Long. B 178 55 W.

True course by chart from A to B is E. by S.; applying variation 21° W. to *right* gives correct magnetic course S. 58° E. = S.E. by E. ⅛ E., and the deviation for this is found to be (Table I) 20½° W., which applied to the *right* of correct magnetic course gives compass course S. 37° 15′ E. = S.E. ¾ S. to be steered from A to B. The distance A to B taken in the dividers and applied to the graduated meridian gives 75 miles, the distance between these two positions.

(II.) With the ship's head on the above-named compass course, D bore by compass N. 53½° W., also E bore S. 45¾° W. by the same compass: find the ship's position.

D, Lat. 51° 38′ N.	Long. 179° 54′ W.
E, Lat. 51° 25′ N.	Long. 179° 8′ W.

The same corrections as in Question I, viz., deviation 20½° W., and variation 21° W. (applied in the usual way as in working the Day's Work), to the compass bearings gives the true bearing of D = S. 85° W. = W. ½ S., and S. 4¼° W. = S. ⅜ W. in latitude 51° 41′ N., longitude 179° 6′ W. Now draw a line running E. ½ N., also another line running N. ⅜ E.; the point of intersection of these two lines gives the position of the ship.

1st Compass bearing	N. 53° 30′ W. (L of N.	2nd Com. bear.	S. 45° 45′ W. (R of S)
Dev. same as in I, allow to *left*	20 30 W. (L)	Deviation	20 30 W. (L)
1st correct magnetic bearing	N. 74 0 W. (L of N)		S. 25 15 W. (R)
Var. same as in I, allow to *left*	21 0 W. (L)	Variation	21 0 W. (L)
Exceeds 90°	N. 95 0 W.	2nd true bearing	S. 4 15 W. =
Subtract from	180 0		S. ⅜ W.
1st true bearing	S. 85 0 W. = W. ½ S.		

(III.) With the ship's head on the above compass course, C bore S. 74° E. by compass, and after continuing the same course 22 miles it bore N. 21¾° E.: find the position of the ship, and her distance from C at the second bearing.

Lat. C 52° 0′ N.	Long. 180° 0′ W.

First turn the two compass bearings into *true* bearings by applying the same corrections and in the same way as in Question II; the *true* bearings of C are thus found to be N. 64½° E. or N.E. by E. ¾ E., and N. 19¾° W. or N. by W. ¾ W.; the work will stand thus:—

1st Compass bearing	S. 74° 0′ E. (L of S)	2nd Com. bear.	N. 21° 45′ E. (R of N)
Dev. same as in I, allow to *left*	20 30 W. (L)	Deviation	20 30 W. (L)
1st Correct magnetic bearing	S. 94 30 E. (L of S)	2nd Cor. mag. b.	N. 1 15 E. (R of N)
Var. same as in I, allow to *left*	21 0 W. (L)	Variation	21 0 W. (L)
Exceeds 90°	S. 115 30 E.	2nd True bear.	N. 19 45 W. =
Subtract from	180 0		N. by W. ¾ W.
1st True bearing	N. 64 30 E. = N.E. by E. ¾ E.		

Next from C draw a line trending S.W. by W. ¾ W., and another trending S. by E. ¾ E. (both opposite to bearing from ship); then lay off the distance sailed, 22 miles, on A towards B, and mark the point to which the foot of the dividers extend *d*. Through *d* draw a line parallel to the line of first bearing, and where this parallel line cuts the line of second bearing is the ship's position at the time of taking the second bearing, viz., latitude 51° 47′ N., longitude 179° 52½′ W., and the distance is found to be 13½ miles.

(IV.) Find the course to steer by compass from A to B (see Question I) to counteract the effect of a current which set S. by E. (true) at the rate of 2 miles an hour, the ship making by log 56 miles in 8 hours; also the distance the ship would make good in 8 hours.

The set of the current being given as true, therefore we lay that off at once without any correction by drawing a line from A running S. by E. The rate of the current being 2 miles an hour, this will give 16 miles drift in 8 hours. Take 16 miles with the dividers from the graduated meridian, and mark off this distance from A on the line representing the set of the current, and call this point *a*. Then take in the compasses the distance 56 miles, also measured on the graduated meridian, which the ship has made by log in the time, and placing one foot of the dividers on *a*, and at the point where the other foot reaches, A B, make a mark, and call it *c*, draw a line from *a* to *c*. The course to be steered is represented by the last line drawn, and placing the edge of the parallel rules over *a c*, and working them down to the centre of the compass on the chart gives E. ⅜ N. = N. 86° E. as the *true* course the ship must make good from A to B to counteract the effect of the current. Correct this course for the variation 21° W., as in Question I, and so get the *correct magnetic course* S. 73° E., then entering Deviation Table, Card I, the deviation is found to be 24½° W., which applied to *right* gives course to steer S. 48½° E. = S.E. ¼ E. Thus:—

True course E. ⅜ N.	N. 86° E. (R of N)
Variation	21 W. (R)
Exceeds 90°	N. 107 E.
Subtract from	180
Correct magnetic course	S. 73 E. (L of S)
Deviation	24½ W. (R)
Compass course	S. 48½ E. = S.E. ¼ E.

S.E. ¼ E. is therefore the course to steer by compass to counteract the effect of the current. The distance, A *c*, taken in the dividers and applied to the graduated meridian (immediately opposite) gives 60 miles as the distance made good from A towards B in the interval.

Ship's Head by Compass.	Deviation	Ship's Head Correct Magnetic.
S.E. by E. .	25° W.	S. 81°15′ E.
S.E. ……	24 W.	S. 69 0 E.

S. 81° 15′ E.   S. 69° E.   25° W.
S. 69 0 E.   S. 73 E.   24 W.
12 0 : 4 :: 1
1
12)4
0⅓

Deviation 24° W.
Correction ⅓
24⅓ W.

EXAMPLE IV.—(Chart used for Sumner's work.)

(I.) Using Deviation Card No. J: find the course to steer by compass from A to B, also the distance (variation 17° E.)

Lat. A 50° 52′ N.	Long. A 179° 40′ E.
Lat. B 49 24 N.	Long. B 178 40 E.

True course by chart from A to B is S.S.W. ⅛ W., applying variation 17° E. to *left* gives *correct magnetic course* S. 6° 54′ W. = S. ⅝ W. The deviation for this (Table I) is 6° E., which applied to the *left* of correct magnetic course gives S. 0° 54′ W. = S. 1° W., the *compass course* to be steered from A to B. The distance A to B taken in the dividers and applied to the graduated meridian (immediately abreast) gives 96 miles, the distance between these two positions.

(II.) With the ship's head on the above-named compass course, a [point] [lighthouse] D bore by compass N. 71° W., and a [point] [lighthouse] E bore N. 19° E. by the same compass: find the ship's position.

Lat. D 50° 37′ N.	Long. 179° 10′ E.
Lat. E 50 40 N.	Long. 179 40 E.

The same corrections as in Question I, viz., dev. 6° E. and var. 17° E., applied (in the same way as in working a Day's Work) to the compass bearings gives the true bearings N. 48° W. = N.W. ¼ W. and N. 42° E. = N.E. ¼ N. respectively. Then draw a line from D running S.E. ¼ E., and another line from E trending S.W. ¼ S.: the point of intersection of these two lines gives the place of the ship in lat. 50° 29′ N., long. 179° 25′ E.

(III). With the ship's head on the above compass course, O bore S. 56° W. by compass, and after continuing on the same course 25 miles it bore N. 54° W.: find the position of the ship and her distance from O at the time of taking the second observation.

Lat. O 50° 22¾′ N.	Long. O 178° 49′ E.

First turn the two *compass* bearings into *true* bearings, by applying the same corrections, and in the same way as in II, above; the true bearings of O are thus found to be S. 79° W. = W. by S., and N. 31° W. = N.N.W. ¾ W; the work is as follows:—

1st Compass bearing of O Deviation, apply to *right*	S. 56° W. (R of S) 6 E. (R)	2nd Com. bear. O Deviation	N. 54° W. (L of N) 6 E. (R)
	—		—
1st Correct magnetic bearing Variation, apply to *right*	S. 62 W. (R of S) 17 E. (R)	2nd Corr. mag. b. Variation	N. 48 W. (L of N) 17 E. (R)
	—		—
1st True bearing of O	S. 49 W. = W. by S.	2nd True bear. O	N. 31 W. = N.N.W. ¾ W.

Then from O draw a line running E. by N. (opposite to W. by S., the bearing from ship), and another line trending S.S.E. ¾ E.; next lay off the distance sailed, 25 miles, on A towards B, and mark the point to which the foot of the dividers extends *d*. Through *d* draw a line parallel to the line of first bearing, and where this parallel line cuts the line of second bearing is the ship's position at the time of taking the second bearing, viz., latitude 50° 4′ N., longitude 179° 7′ W., and the distance from C is found to be 22 miles.

(IV.) Find the course to steer by compass from A to B (see Question I) to counteract the effect of a current which set N. by W. ¼ W. at the rate of 3 miles per hour, the ship making by log 50 miles in 6 hours; also, the distance the ship would then make good in 6 hours towards B.

The *true* course by chart is S. by W., variation (same as in Question I) 17° E. applied to *left* gives correct magnetic course S. 5° 45′ E. = S. ½ E.; the deviation for this (Table I) is found to be 0° 30′ E., which also applied to the *left* gives S. 6° 15′ E. = S. ½ E., easterly, as the *compass course* to steer to counteract the effect of the current. The distance made good from A towards B in the interval is 34½ miles.

In the foregoing examples (I to IV) on the "**Examination in Chart,**" the chart used is supposed to be similar to the one the candidate works the Sumner question upon; but as candidates are now required to work out the questions on either a true or magnetic chart, whichever may be handed to him by the Examiner, accordingly the following examples are intended as exercises in the use of the magnetic chart. Presuming that the same chart is used as before, the candidate must allow for the *variation*, and thus determine the *magnetic North* and *South* points. Taking the following example (V) where the variation is 17° W., or 1½ points W. Before commencing to work this paper the candidate should make a *fleur-de-lis* on the N. by W. ½ W. point on the compass on the chart, and consider that point as *magnetic North*, and all the other points as dependent thereon. It would be advisable to draw with a coloured (*red*) pencil a line from N. by W. ½ W. to S. by E. ½ E. to represent the *magnetic N.* and *S.* line; also, another *red* line joining E. by N. ½ N. and W. by S. ½ S. to represent the *magnetic E.* and *W.* points. Having done this proceed as before, omitting to correct for variation.

EXAMPLE V. (Magnetic Chart).

(I.) Using Deviation Card No. II, find the course to steer by compass from A to B, also the distance. Variation 17° W., or 1½ points W.

A,	Lat. 50° 0′ N.	Long. 4° 0′ W.
B,	Lat. 51° 51′ N.	Long. 6° 0′ W.

Lay the edge of a parallel ruler over A and B, then move the ruler parallel to the line passing through them until an edge pass through the centre of the compass, then the point of the compass coinciding with the edge of the parallels shows the magnetic course from A to B to be N. by W. ½ W.; and, by applying a pair of dividers to the space between them and then to the latitude scale at the side of the chart, the distance is found to be 134 miles.

Magnetic course from A to B = N. by W. ½ W. = N. 17° W.
Deviation, Card II, for N. by W. ½ W. = 0

Compass course N. 17 W.

or, N. by W. ½ W.

(II.) With the ship's head on the above-named compass course, a point C bore by compass S.W., and D bore S.E. by the same compass: find the ship's position.

C,	Lat. 50° 40′ N.	Long. 5° 13′ W.
D,	Lat. 50° 44′ N.	Long. 4° 28′ W.

	C		D
Compass bearing S.W. =	S. 45° W.	S.E. =	S. 45° E.
Deviation	0	Deviation	0
Magnetic bearing	S. 45 W.	Mag. bearing	S. 45 E.
	S.W.		S.E.

Draw a line through C, bearing S.W. *magnetic*, and another through D, bearing S.E. *magnetic;* the point where they meet is the position of the ship on the chart, and it is in latitude 50° 55½′ N., longitude 5° 0′ W.

(III.) With the ship's head as above, a point E bore by compass S. 63¾° W., and after continuing on the same course 28 miles it bore S. 3¾° E.: find the position of the ship, and her distance from E at the time of taking the second bearing.

E,	Lat. 51° 23′ N.	Long. 5° 43′ W.

1st compass bearing	S. 63¾° W.	2nd compass bearing	S. 3¾° E.
Deviation	0	Deviation	0
1st magnetic bearing	S. 63¾ W.	2nd magnetic bearing	S. 3¾ E.
	S.W. by W. ⅝ W.		S. ¼ E. (easterly).

Draw a line through E, bearing S.W. by W. ⅝ W. *magnetic*, and another S. ¼ E. (easterly) *magnetic;* take 28 miles in the dividers, from the latitude scale at the side of the chart, and move a parallel rules parallel to the course from A to B until the dividers reach from the first line of bearing to the second; this is the position of the ship, and she is 29½ miles distance from E, and in latitude 51° 51′ N., and longitude 6° 0′ W.

ADDITIONAL FOR MASTERS.

(IV.) Find the course to steer by compass from A to B (see Question I) to counteract the effect of a current which set N.E. ½ E., correct magnetic, at the rate of 3 miles per hour, the ship making by log 55 miles in 5 hours, also the distance the ship would then make good towards B.

Magnetic course from A to B is N.N.W. ¾ W. = N. 32° W. (L)
Deviation (Card II) 6 W. (R)

Compass course N. 26 W.

or N.N.W. ¼ W.

Distance made good 58½ miles.

EXAMPLE VI. (Magnetic Chart.)

(I.) Using Deviation Card, No. II: find the course to steer by compass from A to B, also the distance. Variation 2½ points W.

A, Lat. 50° 53′ N. Long. 1° 35′ E.
B, Lat. 49° 40′ N. Long. 0° 40′ W.

Before commencing to work this question make a *fleur-de-lis* on the N.N.W. ½ W. point of the compass on the chart, to represent *Magnetic North*, and from this reckon all the other points. Now draw, with a *red* pencil, a line from N.N.W. ½ W. to S.S.E. ½ E., to represent the *Magnetic* N. and S. line; also, another coloured line running N.E. by E. ¾ E. and S.W. by W. ¾ W., to represent the *Magnetic* E. and W. points. Having done this proceed with the work as before, only omitting the correction for variation.

Answer.—Magnetic course W. by S. ¾ S. Deviation 22° 7′ W.
Compass course N. 83° 21′ W. Distance 112 miles.

(II.) With the ship's head on the above-named compass course, a [point] [lighthouse] D bore by compass N.N.E., and E bore N.W. by the same compass: find the ship's position.

D, Lat. 50° 44′ N. Long. 0° 15′ E.
E, Lat. 50° 19½ N. Long. 0° 0′.

D's correct magnetic bearing, North.
E's correct magnetic bearing, N. 67° W., or W.N.W.

Answer.—Latitude 50° 20½′ N. Longitude 0° 33½′ E.

(III.) With the ship's head as above, a [point] [lighthouse] C bore by compass N.N.W., and after continuing on the same course 12½ miles it bore N. by E. ½ E.: find the position of ship, and her distance from C at the time of taking the second bearing.

C, Lat. 50° 55′ N. Long. 0° 58′ E.

1st correct magnetic bearing N. 44° 37′ W. or N.W., nearly.
2nd correct magnetic bearing N. 5° 14′ W. or N. ½ W.

Answer.—Latitude 50° 40½′ N. Longitude 1° 12′ E.
Distance 17 miles.

ADDITIONAL FOR MASTERS.

(IV.) Find the course to steer by compass from A to B (see Question I) to counteract the effect of a current which set S. by E. ¾ E. (magnetic) at the rate of 5 miles per hour, the ship making by log 9½ miles per hour, also the distance the ship would then make good in 3 hours towards B.

Answer.—Magnetic course W. by N. ¾ N. Deviation 18½° W.
Compass course N.W. by W. Distance 23½ miles.

EXAMPLE VII. (Outline English Channel Chart.)*

(I.) Using Deviation Card No. II: find the course to steer by compass from East point of Guernsey to Berry Head, also the distance.

Answer.—Magnetic course N. by W. ½ W. Deviation 0¼° E.
Compass course N. by W. ½ W. Distance 66 miles.

(II.) With the ship's head on the above-named compass course, a [point] [lighthouse] Hanois, West point of Guernsey, bore by compass S.S.W. ½ W., and Casquets bore East by the same compass: find the ship's position.

Magnetic bearing of Guernsey S. 29½° W. is S.S.W. ½ W.
Magnetic bearing of Casquets is East.

Position: Lat. 49° 40′ N. Long. 2° 39′ W.

(III.) With the ship's head as above, a [point] [lighthouse] Casquets bore by compass E.N.E., and after continuing on the same course 14½ miles it bore S.E. by E.: find the position of ship, and her distance from Casquets at the time of taking the second bearing.

1st bearing, magnetic, N. 69° E., or E.N.E. ⅛ E.
2nd bearing, magnetic, S. 54¾° E., or S.E. ⅞ E.

Position at 2nd bearing: Lat. 49° 47½′ N. Long. 2° 48¼′ W.
Distance 17 miles.

ADDITIONAL FOR MASTERS.

(IV.) Find the course to steer by compass from Guernsey to Berry Head (see Question I) to counteract the effect of a current which set E. by S. (magnetic) at the rate of 2½ miles per hour, the ship making by log 45 miles in 5 hours, also the distance the ship would then make good per hour towards Berry Head.

Answer.—Magnetic course N.N.W. ⅝ W. Deviation (Card II) 4¼° W.
Compass course N.N.W. ¼ W. Distance 38 miles.

EXAMPLE VIII. (English Channel Chart.)

(I.) Using Deviation Card No. II: find the course to steer by compass from Bolt Tail to Hanois Light, Island of Guernsey, also the distance.

Answer.—Magnetic course S.S.E. Deviation 7° W.
Compass course S. by E. ⅜ E. Distance 66½ miles.

(II.) With the ship's head on the above-named compass course, a [point] [lighthouse] Bolt Head bore by compass N. 1½° W., and Start bore N.E. by E. ½ E. by the same compass: find the ship's position.

Answer.—Bolt Head, magnetic bearing N. 8½° W. or N. ¾ W.
Start, magnetic bearing N. 55° E. or N.E. ⅞ E.
Latitude 50° 8½′ N. Longitude 3° 43½′ W.

(III.) With the ship's head as above, a [point] [lighthouse] Start bore by compass N.E. by E., and after continuing on the same course 19½ miles, it bore North: find the position of ship, and her distance from Start at the time of taking the second bearing.

Answer.—1st magnetic bearing N. 49° E. or N.E. ⅜ E.
2nd magnetic bearing N. 7° W. or N. ⅝ W.
Latitude 49° 54′ N. Longitude 3° 22½′ W.
Distance 22 miles.

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* In working these questions the English Channel Chart used may be that published by IMRAY & SON, CHARLES WILSON, LAURIE, or the Admiralty, or, in the absence of any of these, the learner may use the outline English Channel chart published to accompany this Guide Book—the results in any case will not differ perhaps more than a mile.

ADDITIONAL FOR MASTERS.

(IV.) Find the course to steer by compass from Bolt Tail to Hanois, Island of Guernsey (see Question I) to counteract the effect of a current which set W. by N. (magnetic), at the rate of 3 miles per hour, the ship making by log 40 miles in 4 hours, also the distance the ship would then make good towards Guernsey.

Answer.—Magnetic course S.E. ¾ S. Deviation 3½ W.
Compass course S. 33° E. or S.E. by S. Distance 32 miles.

EXAMPLE IX.

(I.) Using Deviation Card No. II: find the course to steer by compass from Needles to Cape La Heve, also the distance.

Magnetic course S.S.E. ⅛ S. Deviation 7½° W.
Answer.—Compass course S. 13½° E., or S. by E. ⅛ E.
Distance 93½ miles.

(II.) With the ship's head on the above-named compass course, a [point] [lighthouse] Needles bore by compass N. by W. ¼ W., and St. Catherine's bore E. ¼ S. by the same compass: find the ship's position.

Magnetic bearing of Needles, N. 21½° W., or N. by W. ⅞ W.
Magnetic bearing of St. Catherine's, N. 85½° E., or E. ⅜ N.
Answer.—Latitude 50° 33′ N. Longitude 1° 25′ W.

(III.) With the ship's head as above, a [point] [lighthouse] St. Catherine's bore by compass S.E. by E. ⅜ E., and after continuing on the same course 19 miles, it bore N. ¼ E.: find the position of ship, and her distance from St. Catherine's at the time of taking the second bearing.

1st magnetic bearing S. 68° E., or E.S.E.
2nd magnetic bearing N. 4¾° W., or N. ⅜ W.
Answer.—Latitude 50° 21½′ N. Longitude 1° 8′ W.
Distance 15½ miles.

ADDITIONAL FOR MASTERS.

(IV.) Find the course to steer by compass from the Needles to Cape La Heve (see Question I) to counteract the effect of a current which set S.E. by S. (magnetic), at the rate of 2 miles per hour, the ship making by log 40 miles in 5 hours, also the distance the ship would then make good in 5 hours towards Cape La Heve.

Answer.—Magnetic course S.S.E.
Compass course S. 15½ E., or S. by E. ⅜ E.
Distance 50 miles.

SOUNDINGS.

210. In the open sea the tide requires about six hours and a quarter to rise from low to high water, and an equal interval to fall from high to low water. If the rise or fall was an uniform quantity throughout, by simply taking a proportionate part of the rise or fall due to the time of tide, we should at once obtain the quantity required to reduce the soundings to the low water of that day. But the water does not rise in equal proportions, the rise during the first and last hours being very small (about one-sixteenth of the whole range); in the second hour there is a considerable increase of rise;

in the third and fourth hours a still greater increase of rise; and then the rise begins to take off in the same proportion as it increased.*

The correct amount for every half-hour, and for various ranges, is given in the "Tide Tables for the English and Irish Ports for 1885," (p. 98, Table B), published by the Hydrographic Office, Admiralty.†

211. As the soundings upon the chart are all referred to or measured downwards from the mean level of low water of *ordinary* spring tides,‡ casts of the lead taken at any other time of the tide, or any other day than full and change, will exceed the depth marked on the chart (except when it happens to be low water of *greatest* spring tides). It is necessary for the seaman to be able to calculate the difference between the actual depth obtained by means of his lead and that marked on his chart, in order to the identification of his ship's place, more especially when the range of the tide is considerable, and the depth not great. Also, when about to enter a port in a vessel whose draught of water is nearly equal to the depth, it is necessary to find the height of the tide as exactly as circumstances will permit.

212. Two classes of questions may be proposed in reference to this subject—*firstly*, to find the depth of water at a given place and time; *secondly*, having obtained the actual depth by a cast of the lead, to find the sounding on the chart corresponding thereto, and thence to identify the ship's place. Both these classes of questions require us to know the *time* of high water and the *range* of the tide on the given day; and for this purpose almanacs are published. At the Board of Trade Examination Candidates are required to use the "Tide Tables" published by the Admiralty. In this book are given the times of *high water* and the *height of the tide* for every day in the year, at each of the principal ports in Great Britain.

213. To find how much we must subtract from a cast of the lead, in order to a comparison with the soundings marked on the chart.

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* The reader may obtain an idea of this law, sufficiently exact for practical purposes, in the following manner:—Describe a circle, and divide the circumference into six equal parts on each side, corresponding to the hours of the tide; then divide the diameter into proportional parts, corresponding to a given (assumed) range of tide. Connect the segments of the circle by straight lines drawn across the figure, when it will be perceived that they intersect the diameter at certain divisions of the range. These are the correct quantities respectively due to each hour's rise or fall of such a tide from low to high water, and *vice versa.* An examination of these quantities will show, that in the first hour of the tide the rise is equal to one-sixteenth of the whole range; at two hours from low or high water, the tide has risen or fallen *one-fourth* of the whole range; at three hours it has risen just *half* its range; at four hours it has risen *three-fourths* of the whole range; at five hours to within a *sixteenth* of the whole range. The above method, which is constructed on principles theoretically correct, will represent with sufficient exactness all that is necessary for practical purposes.

† Table XIX, Raper, which the author, in 1847, computed for Raper's work, also shows the space through which the surface of the water rises and falls at given intervals from high or low water.

‡ On most charts the soundings expressed are reduced to low water of *ordinary spring tides;* but in some charts, however, the soundings are reduced to the low water of extraordinary spring tides—such, for example, is the case on the chart of Liverpool, surveyed by Captain Denham, R.N., the soundings on which are reduced to a spring range of thirty feet, while the mean spring range for that place, as deduced from observations made for two years at the Tide Gauge, St. George's Pier, is 26 feet.

CASE I.

When the place given is one of the Standard Ports for Reference, proceed by

RULE LXXXVI.

1°. *Open the* Admiralty Tide Tables *at the proper month; and in the column under the head of the place near your position, and opposite the day of the month, take out the "time" of high water in the morning or afternoon, as the case requires, and also from the adjoining column, under "height," take out the height of the tide.*

2°. *Next, underneath the time of high water place the time at ship, and take the* difference *and call it* "time from high water."

3°. *From the* height of tide *subtract the half mean* Spring Range, *which stands at the foot of the column.*

The remainder is the *half range* of the day.

4°. *Enter* Table B, page 98, Admiralty Tide Tables, *and* under *the time from high water, and* opposite *the half range for the given day, take out the correction corresponding thereto.*

Table B, the use of which, in many cases, involves troublesome interpolations, can be dispensed with by using the following rule:—Take the difference between the time *from* high water and 3 hours; reduce this into minutes (by multiplying by 60), and divide these minutes by 2. Take the quotient thus found as a *course* in Table II (NORIE or RAPER), and the height above half tide (reduced to inches) as a *distance*, and take out the corresponding *departure*, which consider as inches, and bring it into feet and inches by dividing by 12.

5°. Add *the correction to the mean half Spring Range marked on the chart when* time *from high water is* less *than* 3 hours, *but* subtract *if* more *than* 3 hours.

The result is the excess *of the* sounding observed *above the* sounding recorded *on the chart, or* is the height of the tide above zero.

6°. Subtract *this last from the sounding shown by the* lead, *the* remainder *is the sounding shown by the* chart.

NOTE I.—When it happens to be an *extraordinary* low ebb tide, the quantity given in Table B will be *greater* than the half mean spring range, and will be *subtractive*. In such cases, subtract the half mean spring range from the correction by Table B, and *add* the result to the soundings by lead; the sum will be the sounding on the chart.

EXAMPLES.

EX. 1. 1885, September 27th, at $2^h 52^m$ P.M., a ship off Liverpool strikes soundings in 8 fathoms: required the corrected soundings to compare with the chart. (The half spring range by Captain DENHAM's chart is 15 feet).

Admiralty Tide Tables (page 70); time of high water at Liverpool, September 27th, 1885	0^h	52^m P.M.
Time of sounding	2	52
Time from high water	2	0
	ft.	in.
Height at Liverpool	26	11
Half mean spring range	13	9
Half range of the day (or height above mean level)	13	2
In Table B, page 98, under 2^h, opposite 13 ft. 2 in. stands *add*	6	7
Half spring range by chart	15	0
Correction 3½ fathoms, nearly, or	21	7

Or, proceeding thus:—

Time from high water	$2^h\ 0^m$	Half range for day	13 ft. 2 in.
Subtract from	3 0		12
	1 0		158 inches.
	60		
	2)60		
	30°		

Course 30° and distance 158 give dep. 79·0 = 6 ft. 7 in. (as before).

Depth by lead	8 fathoms.
Correction	3½ „
Showing the depth for comparison	4½ „

Whence the depth to compare with the chart is only 4½ fathoms instead of 8 fathoms.

Ex. 2. 1885, December 23rd, $7^h\ 15^m$ A.M., a vessel anchored off Weston-super-Mare in 6½ fathoms; at low water the vessel was "high and dry:" required the cause of this. (Half spring range by chart 23 feet).

By Table: December 23rd, the time of high water at Weston-super-Mare	$7^h\ 39^m$ A.M.	
Time of anchoring	7 15	
Time before high water	0 24	
	ft.	in.
Height of tide by Tables	39	2
Half spring range	18	7
Half range	20	7
* By Table B, 24^m and half range 20 feet 7 inches give *add* ..	20	2
By chart: half spring range	23	0
Correction to low water	43	2
Sounding 6½ fathoms, or	39	0
	4	2

* $0^h\ 0^m$ and 20 ft. give 20 ft. 0 in.
0 30 20 19 4
Change in 30^m 8
Change in 24^m 4
$= \frac{24}{30} = \frac{4}{5}$
5)32
− 6

$0^h\ 0^m$ and 20 ft. 20 ft. 0 in.
21 21 0
Change for 12 in. 1 0
Change for 7 in. 7
12)7 0
+ 0 7

$0^h\ 0^m$ and 20 ft. 0 in. 20 ft. 0 in.
24 7 − 6
+ 7
Corr. for $0^h\ 24^m$ and 20 ft. 7 in. } 20 1

Time of H.W., Weston-super-Mare	$7^h\ 39^m$ A.M.	Ht. of tide, Weston-super-Mare	39 ft. 2 in.
Time of sounding	7 15	Half spring range	18 7
Time from high water	0 24	Half range per day	20 7
	3 0		12
	2 36		247 inches.
	60		
		*Correction	+ 20 ft. 2 in.
	2)156	Spring range, chart	23 0
	78°	Correction to low water	43 2
		Sounding 6½ fathoms, or	39 0
			4 2

* Course 78° and distance 247 give dep. 241·6 = 20 ft. 2 in.

Water below the sounding; or, the ship is found to be 4 feet 2 inches dry at low water.

CASE II.

When the given place is **not** a Standard Port for Reference, but is given in the Table of Tidal Constants, proceed as follows:—

RULE LXXXVII.

1°. *Find the given place in the* "Table of Tidal Constants" (Admiralty Tide Tables, pages 104-108), *and note the Standard Port for Reference; also take out the Constants for Time and Height.*

2°. *By the usual method of finding the time of high water at a given place by means of the* Standard Port for Reference, *and the* Time Constants, *find the time of high water* **nearest** *to the time of sounding, as given in the question. Take the difference between this time of high water and the given time of sounding.*

3°. **To find the Half mean Spring Range.**—*Seek in the latter part of the* Tide Table (pages 191-234) *for the given place; take out from the middle column the* mean spring range, *divide this by* 2, *the* quotient *is the* half spring range *of the place where the cast was taken.*

Then proceed as in Case I.

EXAMPLE.

Ex. 1. 1885, December 8th, at $3^h 55^m$ P.M., being off Cape Grisnez, took a cast of the lead: required the correction to be applied before comparing with soundings.

Here the Port for Reference is Dover, and the Tidal Constant is + $0^h 15^m$ (page 108, *Admiralty Tide Tables*). The A.M. tide at Dover (page 91, *Tide Tables*) is marked —— (blank), and the P.M. tide is $0^h 5^m$ P.M., to which the Tidal Constant, $0^h 15^m$, being *added* gives $0^h 20^m$ as the P.M. time of high water at Cape Grisnez. Opposite the P.M. tide at Dover, under Height, in *Admiralty Tide Tables*, is 17 ft. 10 in., which is the height of high water for that tide, to which add the Constant for height; the result is the height of high water at Cape Grisnez, from which subtract the half mean spring range for Cape Grisnez (see page 206, *Admiralty Tide Tables*); the result is the height above half tide. Now enter Table B (page 98 of *Tide Tables*) with Time from High Water along the top, and height above half tide at the side, and we obtain 2 ft. 9 ins. to be *subtracted* from the sounding shown by the lead.

The work of the above example appears as below:—

From page 108, *Admiralty Tide Tables.* } Time Constant + $0^h 15^m$
Height Constant + 2 ft. 4 ins.
Port for Reference—DOVER.

Time of high water, Dover, December 8th	$0^h 5^m$	P.M.
Constant	+ 0 15	
Time of high water, Cape Grisnez, Dec. 8th .. No A.M., and	0 20	P.M.

			ft.	in.
Time of sounding	$3^h 55^m$	Height of H.W., Dover, by Tables, Dec. 8th	17	10
Time H.W., Grisnez	0 20	Height Constant for Grisnez	+ 2	4
Time from H.W.	3 35	Height high water Grisnez	20	2
Subtract	3 0	Half mean spring range (p. 206, *Tide Tables*) *subt.*	10	9
	0 35	Height above half tide	9	5
	2)35		12	
	$17\frac{1}{2}$°		113 ins.	

Corr. $17\frac{1}{2}$°, and height above half tide (9 ft. 5 in. =) 113 as distance, gives dep 34 in. = 2 ft. 10 in., the correction; *subtract* 3^h from half spring range, because time from high water *more* than 3^h.

Otherwise, using Table B:—

Half spring range	10 ft. 9 in.
* By Table B: 9 ft. 5 in. at $3^h\ 35^m$ from high water	2 9 *subt.*
Correction to be applied to sounding	8 0

* $3^h\ 30^m$ and 9 ft. 2 ft. 4 in.
4 0 9 4 6
Diff. for 30^m 2 2
+ 0 4

$3^h\ 30^m$ and 9 ft. 2 ft. 4 in.
3 30 10 2 7
0 3
5
12)15
1 +

$3^h\ 30^m$ and 9 ft. 2 ft. 4 in.
0 5 5 in. + 4
+ 1
Correction 2 9

In the examples above we have always had a Constant for time and a Constant for height given, but an examination of the Table of Tidal Constants will show that for some places only a constant for time is given.

RULE LXXXVIII.

To find the Constant for height proceed as follows:—*Turn to the* Tide Tables (pages 191-234) *and take out the mean spring ranges for both places, and take the difference between the spring ranges at the* given *port and at the* Port for Reference; this is the Constant for height. *Mark this Constant* + (add) *if the range at the place* required *is* greater *than at the* Port for Reference, *and* — (subtract) *if the range at the place* required *is* less.

EXAMPLE.

Ex. 1. 1885, April 16th, $8^h\ 20^m$ A.M., being off Lundy Island by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead-line before comparing it with the depth marked on the chart.

Here the Standard Port for Reference is WESTON-SUPER-MARE, and the Time Constant is — $1^h\ 39^m$ (page 105, *Admiralty Tide Tables*). The A.M. tide at Weston-super-Mare is $7^h\ 25^m$ A.M. (page 31, *Admiralty Tide Tables*), from which the Time Constant, $1^h\ 39^m$, being *subtracted* gives time of high water at Lundy $5^h\ 46^m$ A.M., and the difference between this time and $8^h\ 20^m$ A.M., the time of sounding, gives time from high water. To *find* the height Constant we proceed as follows:—Look in the *Admiralty Tide Tables*, and at page 233 we find the mean spring range at Weston-super-Mare is 37 ft. 0 in., and at page 213 of the same tables we find the mean spring range at Lundy to be 27 ft. 0 in.; the difference of these is 10 ft. 0 in., and must be marked — (*subt.*), because the spring range at Lundy is less than the spring range at Weston-super-Mare. Opposite the A.M. tide at Weston-super-Mare, and in the adjoining column, under height, in *Admiralty Tide Tables*, is 38 ft. 11 in., which is height of high water for that tide, from which subtract the Constant for height (— 10 ft. 0 in.); the result (28 ft. 11 in.) is the height of high water at Lundy; from this last *subtract* the half mean spring range at Lundy (see *Admiralty Tide Tables*) = (27 ft. 0 in. ÷ 2) = 13 ft. 6 in.; the result, viz., 15 ft. 4 in., is height above half tide. Enter Table B, page 98 of *Tide Tables*, with the Time from High Water, $2^h\ 34^m$, at the top of the column, and 15 ft. 4 in., the height above half tide at the side, we obtain 3 ft. 5 in. to be *added* (time from high water being *less* than 3 hours) to the half mean spring range; the result is 16 ft. 11 in., and is the *correction* to be *subtracted* from the sounding. The work will stand as follows:—

Time H.W. Weston-super-Mare, April 16th	7^h 25^m A.M.
Constant	— 1 39
Time H.W. Lundy, April 16th	5 46 A.M.
Time of sounding	8 20 A.M.
Time from high water	2 34
Subtract from	3 0
	2)26
	13°

Corr. 13°, and dist. 185, Table II, gives dep 42′ = 3 ft. 6 in. to be *added* to half mean range, because time from high water is less than 3 hours.

To find Constant for Height.	ft.	in.
Weston-super-Mare, spring range, *Admiralty Tide Tables*, page 233	37	0
Lundy Island, spring range, p. 213	27	0
Constant for height	— 10	0
Spring range at Lundy Island, *Tide Tables*, page 213	27	0
Half spring range	13	6
Height of tide, Weston-super-Mare, April 16th	38	11
Constant for Lundy	— 10	0
Height at Lundy	28	11
Half spring range	13	6
Height above half tide	15	5
	12	
	185 in.	

Half spring range at Lundy	13 ft.	6 in.
* Table B: 2^h 34^m and 15 ft. 5 in.	3	6 *add.*
Correction to be applied to sounding	17	0

* 2^h 30^m and 15 ft. give	3 ft.	11 in.
3 0	0	0
Change for 30^m	3	11
	12	
30 : 4 :: 47	47	
	4	
	30)188	
Change for 4^m =	— 6	

2^h 30^m and 15 ft.	3 ft.	11 in.
„ 16	4	2
Change for 12 in.	+	3
Change for 5 in.	+	1

2^h 30^m and 15 ft.	3 ft.	11 in.
0 4	— 0	6
	3	5
Corr. for 5 in.	+	1
Corr for 2^h 34^m and 15 ft. 5 in.	3	6

CASE III.

When the given place is **not** a Standard Port for Reference, and both Constants with respect to such are not given.

RULE LXXXIX.

1°. **To find the Constant for Time.**—*Seek out that one of the Standard Ports for Reference which is nearest the given place. Next, take out the Time of High Water, Full and Change, for the* Standard Port *and for the* given place *(Admiralty Tide Tables, pages* 131-234*) and take their* difference, *which mark* + (add) *if the* Full *and* Change *at the* given place is greater, *but* — (subt.) *if it is* less *than the* Standard Port.

2°. **To find the Constant for Height.**—*Proceed as directed in* Rule LXXXVIII, page 310.

3°. *Next, by the usual method find the time of high water* **nearest** *to the time of sounding, as given in the* question, and proceed as in Case II, Rules LXXXVII and LXXXVIII.

EXAMPLE.

Ex. 1. 1885, November 2nd, at 2^h 15^m A.M., mean time at ship, off Ile de Bas, took a cast of the lead: required the correction to be applied to the depth obtained by lead-line before comparing it with depth marked on the chart, Here the Standard Port for Reference is BREST, and both Constants for time and height must be found.

At page 196, *Admiralty Tide Tables*, we find time of high water, full and change, at Brest to be $3^h 47^m$, and spring range 19 ft. 0 in.; again, at page 194 of same tables, the time of high water, full and change, at Ile de Bas is found to be $4^h 49^m$, and spring range 23 ft. 0 in.; we next take difference of times of full and change, which is $1^h 2^m$, which we mark +, because full and change, Ile de Bas, exceeds that at Brest. The difference of the spring ranges is 3 ft. 0 in., and is marked +, because the spring range at the given place is *greater* than that at Brest. The remaining part of the work as Case II.

Brest, time H.W., full and change	$3^h 47^m$ page 196.	Spring range	19 ft. 0 in.
Ile de Bas, „ „	4 49 „ 194.	„	23 0
Constant	+ 1 2	Constant	+ 4 0

Half mean spring range, Ile de Bas, = (23 ft. 0 in. ÷ 2) = 11 ft. 6 in.

Time H.W., Brest, Nov. 1st	$11^h 28^m$ P.M.	Height of H.W. at Brest	15 ft. 1 in.
Constant	+ 1 2	Constant	+ 4 0
Time H.W., Ile de Bas, Nov. 2nd	0 30 A.M.	Height at H.W., Ile de Bas	19 1
Time of sounding	2 15 A.M.	Half spring range *subt.*	11 6
Time *from* H.W.	1 45	Height above half tide	7 7
Subtract from	3 0		12
	1 15		91 inches.
	60		
	2)75		
	37½°		

Course 37½° and distance 91 gives departure 55·4 = 4 ft. 7 in. to *add* to half spring range, because time from high water is *less* than 3 hours.

Half mean spring range	11 ft. 6 in.
Correction (found as above)	+ 4 7
Correction for sounding	16 1

Otherwise, using Table B:—

Half mean spring range	11 ft. 6 in.
Table B $1^h 15^m$ and 7 ft. 7 in.	+ 4 7
Correction for soundings	16 1

$1^h 30^m$ and 7 ft.	4 ft. 11 in.	Corr. for $1^h 30^m$ and 7 ft. =	4 ft. 11 in.	Corr. $1^h 30^m$ and 7 ft.	4 ft. 11 in.
2 0 7	3 6	Corr. for 1 30 8	5 8	Corr. 0 15	— 0 9
Change 30^m	— 1 5	Change for 12 in.	0 9	Corr. for 7 in.	+ 0 5
Change 15^m	— 0 9	Change for 7 in.	+ 0 5	Corr. $1^h 45^m$ and 7′ 7″	4 7 +

EXAMPLES FOR PRACTICE.

1. 1885, June 16th, at $5^h 22^m$ A.M., mean time at ship, off Brest, took a cast of the lead.
2. 1885, June 9th, at $7^h 18^m$ P.M., mean time at ship, off Portsmouth, took a cast of the lead.
3. 1885, June 19th, at $6^h 38^m$ A.M., mean time at ship, off Harwich, took a cast of the lead.
4. 1885, Oct. 23rd, at $11^h 18^m$ P.M., mean time at ship, off Sunderland, took a cast of the lead.
5. 1885, June 5th, at $5^h 2^m$ A.M., mean time at ship, off Beaumaris, took a cast of the lead.
6. 1885, June 1st, at $3^h 32^m$ P.M., mean time at ship, off Lamlash, took a cast of the lead.
7. 1885, June 5th, at $7^h 27^m$ P.M., mean time at ship, off Scarbro', took a cast of the lead.
8. 1885, August 11th, $0^h 50^m$ P.M., mean time at ship, off Lerwick, took a cast of the lead.
9. 1885, June 20th, at $3^h 33^m$ P.M., mean time at ship, off Coleraine, took a cast of the lead.

(NOTE.—Look in page 200 and 213 of *Admiralty Tide Tables* for the time of H.W. at Coleraine, full and change, and spring rise).

MAGNETISM.

MAGNETIC ATTRACTION AND REPULSION.

214. Magnetism.—Magnetism is that branch of physical sience which treats of the nature and properties of magnets and of their action on each other. The term magnetism is also used to designate the force which produces the effects called magnetic.

215. Natural Magnets,* or Lodestones.—Natural magnets, or lodestones, are exceedingly rare, although a closely allied ore of iron, capable of being strongly acted upon by magnetic forces, and hence called magnetic iron ore (known to mineralists as *magnetite*), is found in large quantities in Sweden, Norway, Spain, Arkansas, the Isle of Elba, and elsewhere. This mineral—the lodestone of the ancients—is composed of the peroxide and the protoxide of iron in combination with a small quantity of earthy substance having the chemical composition $Fe_3\,O_4$. It is a dark gray colour, and the fresh fracture possesses a metallic lustre. It frequently occurs in crystals, the usual form being the octrahedron.

216. Artificial Magnets.—When a piece of steel, which has been properly hardened and tempered, is *rubbed* with a piece of *lodestone*, or by any other magnet, or when a current of electricity is passed round it by means of a coil of insulated wire, it becomes a more or less powerful magnet: such a magnet is termed an *artificial* magnet.

Artificial magnets are permanent or temporary as they retain their magnetism or not, after being removed from the source by which they acquired it.

The most usual form of artificial magnets is that of a bar or horse-shoe. When single they are termed *simple* magnets, when consisting of several joined together, so that their **similar** poles are adjacent, they are termed *compound* magnets: the latter are sometimes designated **magnetic batteries.**

A magnetic battery is, therefore, simply a bundle of magnets with their similar ends placed together.

A Bar Magnet is simply a bar of cast iron or steel properly hardened, tempered, and magetised.

The needle or bar of steel in the Mariner's Compass is an artificial magnet.

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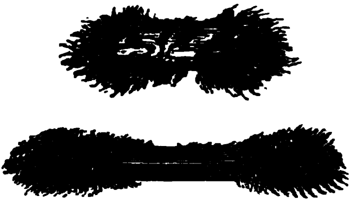
* The term Magnet (*Magnis Lupis*) was given by the ancients to certain black stones found in various parts of the world, notably at Magnesia in Asia Minor, which possessed the property of attracting small pieces of iron and steel. This magic property as they deemed it, made the magnet stone famous; but it was not until the tenth or twelfth century that such stones were discovered to have the still more remarkable property of pointing north and south when hung up by a thread. This property was turned to advantage in navigation. Its various names are interesting. In Pliny's time it was called *ferrum vivum*, quick iron; the Chinese know it as *tohu-chy*, the directing stone; and similarly in the Swedish it is *segel-sten*, the seeing stone; in Islandic, *liederstein*, the leading stone; and in English the *lodestone* (from Sax. to lead).

217. Poles and Neutral Line.—The property of attracting iron is very unequally manifested at different points of the surface of a magnet.

If, for example, an ordinary bar-magnet be plunged in iron filings these become arranged round the ends of the bar in feathery tufts which decrease towards the middle, which is bare, as in the lower diagram, Fig. 63. If the magnet is very thick in proportion to its length we may have filings adhereing to all parts of it, but the quantity diminishes rapidly towards the middle, as in the upper diagram, Fig. 63. The name *poles* is used in a somewhat loose sense to denote the two terminal portions of a magnet, or to denote two points, not very accurately defined, situated in these portions, and where the attraction is greatest. The middle portion, where there is no visible magnetic force, and to which the filings refuse to adhere, is called the *neutral line*.

Fig. 63.

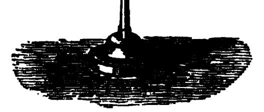


218. Axis and Equator.—The shortest line joining the two poles is called the *axis* of the magnet: in a horse-shoe magnet the axis is in the direction of the keeper. The plane at right-angles to the axis and passing through the neutral line is called the *equator* of the magnet.

219. Consequent Poles.—Every magnet, whether natural or artificial, has two poles and a neutral line; sometimes, however, in magnetising bars and needles poles are produced lying between the extreme points. These intermediate points are called *consequent poles*.

220. Magnetic Needle.—Any magnet freely suspended near its centre of gravity is usually called a *magnetic needle*. One of its most usual forms is that of a very elongated rhombus of thin steel, having very near its centre a concavity or *cup*, by means of which it can be balanced on a point. When it is thus balanced horizontally it does not, like an ordinary piece of matter, remain in equilibrium in all azimuths,* but assumes one particular direction, to which it always comes back after displacement. In this position of stable equilibrium one of its ends points to magnetic north and the other to magnetic south, which differ in general by several degrees from geographical (or true) north or south. This is the principle on which compasses are constructed.

Fig. 64.



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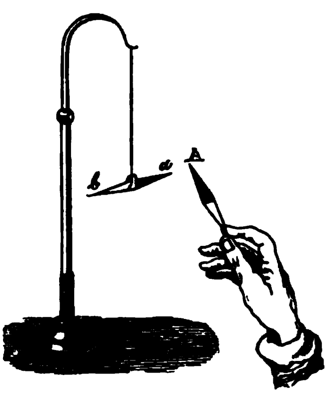
* All lines in the same vertical plane are said to have the same azimuth. Azimuthal angles are angles between vertical planes, or between horizontal lines. The azimuth of a line, when stated numerically, is the angle which the vertical plane containing it makes with a vertical plane of reference, and this latter is usually the plane of the meridian. Some readers may be glad to be reminded that by the plane of the *meridian* is meant a vertical plane passing through the place of observation, and through or parallel to the earth's axis. A horizontal line in this plane is a meridian line.

221. Mutual Action of Poles.—The two poles of a magnet appear identical when they are brought in contact with iron filings, but this indentity is only apparent.

On presenting one end of a magnet to one end of a needle thus balanced we obtain either repulsion or attraction, according as the pole which is presented is similar or dissimilar to that to which it is presented. For when a small magnetic needle *a b* (Fig. 65) is suspended by a fine thread and the north pole, A, of another needle is brought near its north pole, *a*, a repulsion takes place. If, on the contrary, A is brought near the south pole, *b*, of the movable needle the latter is strongly attracted. Hence, these two poles, *a* and *b*, are not identical, for one is repelled and the other attracted by the same pole of the magnet A. It may be shown in the same manner that the two poles of the latter are also different by successively presenting them to the pole, *a*, of the movable needle. In one case there is repulsion, in the other attraction.

Fig. 65.



Hence the following law may be enunciated:—

Poles of contrary *names* **attract** *one another, and poles of the* same *name* **repel** *one another.*

But further, the forces exerted by the two poles of the same magnet are *equal* as well as opposite. This may be shown by bending a magnet so as to bring the opposite poles nearly into contact. The action of the two poles upon a distant point will be found to neutralise one another.

The opposite actions of the north and south poles may be shown by the following experiment:—A piece of iron, a key for example, is supported by a magnetised bar. A second magnetised bar of the same dimensions is then moved along the first so that their poles are contrary. The key remains suspended so long as the two poles are at some distance, but when they are sufficiently near the key drops, just as if the bar which supported it had lost its magnetism. This, however, is not the case, for the key would be again supported if the first magnet were presented to it after the removal of the second bar. The attraction which a magnet exerts upon iron is reciprocal,

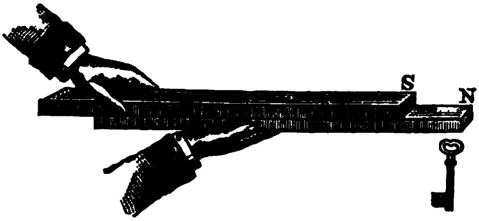


Fig. 66.—Showing the mutual action of two *dis*-similar poles in lessening the Portative and Attractive powers of magnets.

which is, indeed, a general principle of all attractions. It is easily verified by presenting a mass of iron to a movable magnet when the latter is attracted.

222. Magnetic Force.—The force with which a magnet attracts or repels another magnet, or any piece of iron or steel, is called *magnetic force.* The force exerted by a magnet upon a piece of iron or on another magnet is not the same at all distances, the force being greater when the magnet is nearer, and less when the magnet is further off. In fact the attraction due to a magnet pole falls off inversely as the square of the distance from the pole.

Whenever a force acts thus between two bodies it acts on both of them, tending to move both. A magnet will attract a piece of iron, and a piece of iron will attract a magnet. This may be shown by fixing a magnet upon a piece of cork and floating it on a basin of water, it will be found to move across the basin when a piece of iron is held near. A compass needle thus floated turns round and points north; but it does not rush towards the north as a whole, nor towards the south. The reason of this will be explained later. The action and reaction are then equal for magnetic forces.

223. Attraction across bodies.—Magnetic attraction and repulsion are exerted without modification through any body which may be interposed, provided it be not magnetic. Thus, a small cylinder of soft iron is readily attracted by a magnet through a plate of glass or piece of wood (Fig. 67); and similarly, of course, the magnetic needle may be attracted (Fig. 68). A magnet sealed up in a glass tube still acts as a magnet. A magnet put into a brass vase has been found to attract iron filings through the brass. Across water, vacuum, and all known substances, the magnetic forces will act, with the single exception, however, that magnetic force will not act across a *screen of iron* or other magnetic material. If a small magnet is suspended inside a hollow ball made of iron, no outside magnet will affect it. A hollow shell of iron will, therefore, act as a *magnetic case* and screen the space inside it from magnetic influence.

Fig. 67.

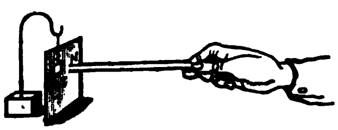
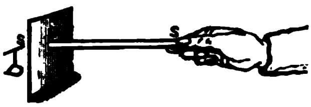


Fig. 68.



224. Names of Poles.—There would, therefore, appear to be two opposite kinds of magnetic poles, which attract and repel one another in very much the same way as the two opposite kinds of electricity do; and one of these kinds of magnetism appears to have a tendency to move toward the north and the other to move toward the south. Regarding the earth, in a broad sense, as a magnet, having one pole in the northern and the other in the southern hemisphere, and since poles which *attract* one another are *dissimilar*, it follows that the magnetic pole of the earth which is situated in the northern hemisphere is *dissimilar* to that end of a magnetised needle which points to the north. Hence great confusion of nomenclature has arisen, the usage of the best writers being opposite to that which generally prevails.

Popular usage in this country, however, calls the end or pole which points to the north the *north pole*, and that which points to the south the *south pole*; and it is usual for makers of magnets to mark the north-seeking pole with a letter N. It is, therefore, called the "marked" pole to distinguish it from the south-pointing or unmarked pole.* It is desirable to adopt the nomenclature of Sir B. G. Airy, and call that pole of a magnet or compass needle which would, if the magnet were suspended, tend to turn to the north, or the "north-seeking" pole, the *red* pole, and the other, or the "south-seeking" polo, the *blue* pole.

225. Magnetic Induction.†—When a piece of iron is in contact with a magnet, or even when a magnet is simply brought near it, it becomes itself, for the time, a magnet with two poles and a neutral portion between them. Thus, if the north pole of a magnet be brought near to the end of a small bar of iron, that end becomes a south pole, while the remote end of the bar becomes a north pole. The opposite effect will take place when the south pole of the magnet is presented. And, in general, the magnetism induced in the bar is such that a *contrary* pole is developed at the end *next* the inducing pole of the magnet, and a similar pole at the remote end. These facts may be shown by means of the compass needle. The end of the bar remote from the acting pole attracts one of the poles of the needle and repels the other in a manner precisely similar to the acting pole itself. The magnetism developed in the end of the bar next the acting pole is not so easily manifested, for the magnetic needle placed near that end will be acted on directly by the pole of the magnet itself, as well as by the induced pole of the iron bar, and the result will be complicated by the joint action.

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* There is some confusion in writers on the subject on this point. The cause of the confusion is this:—If the north-pointing pole of a needle is *attracted* by magnetism residing near the north pole of the earth, the law of attraction (that *unlike poles attract*) shows us that these two poles are really magnetically of opposite kinds. If we call that north magnetism which is at the north pole of the earth we must say that the north-seeking end of the needle contains south magnetism. And if we call that north magnetism which points to the north then we must suppose the magnetic pole at the north pole of the earth to have south magnetism in it. In either case then there is a difficulty. Sir W. Thomson calls the north seeking pole a "true south" pole and the other the north pole, because the former is similar to the south and the latter to the north pole of the earth. In like manner most French writers call the north seeking pole of a needle the *austral* and the other the *boreal* pole. Faraday, to avoid the ambiguity which has attached itself to the names north and south pole, calls the north-seeking end the *marked* and the other the *unmarked* pole. Sir G. Airy, for a similar reason, employs in his *Treatise on Magnetism* the distinctive names *red* and *blue*, to denote respectively the north-seeking and south-seeking ends; these names, as well as those employed by Faraday, being purely conventional, and founded on the custom of marking the north-seeking end of a magnet with a transverse notch or a spot of red paint. For experimental purposes it is usual to paint the two ends of a magnet of different colours, the north-seeking end being coloured *red*, and the south-seeking end *blue*; but here again, strangely enough, authorities differ, for in the collection of apparatus at the Royal Institution and Royal School of Mines the colours are in exactly the opposite way to this, which, as just stated, is due to Sir G. Airy. Maxwell and Jenkin, in a report to the British Association, call the south-seeking pole of a needle *positive* and the north-seeking pole *negative*.

† Airy in his "*Treatise on Magnetism*" defines soft iron as "Either malleable iron which has not been subjected to any violence when cold or cast iron." In the Admiralty Manual it is thus defined:—"Soft iron is iron which becomes instantaneously magnetised by induction when exposed to any magnetic force, but which has no power of retaining magnetism, and it has, therefore, no independent magnetism; all its magnetism is transient induced magnetism."

The iron bar, thus rendered magnetic, exhibits all the other properties of a magnet. It attracts iron, the attractive force increasing from the centre to the two poles. If we scatter filings over the iron they will adhere to its ends, as shown in Fig. 69, as in the case of the original magnet, the effect being only complicated by the action of the inducing pole. If we take away the influencing magnet the filings will fall off, and the iron will retain either no traces at all, or only very faint ones of its magnetisation.

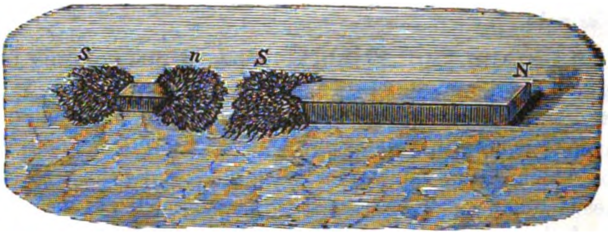

Fig. 69.—Showing Magnetic Induction. N S, North and South Poles of a Bar Magnet. *n s*, North and South Poles of a piece of Soft Iron magnetised *inductively* (at a distance) by the permanent bar magnet. The *magnetised* state of the *soft iron* bar is shown by the adhesion of the iron filings.

But if the magnet is turned end for end, and the position of the poles changed, then the marked end (N. or red role) of the magnet, will instantly induce in the ends of the soft iron poles of a character opposite to those they previously had, which may be easily tested by holding a suspended magnetic needle to the outermost ends of the soft iron, and the experiment is an illustration of the effect of *transient induced magnetism.*

Again, if we lay two magnets in a line at a short distance apart, with *unlike* poles turned to one another, and place a thin bar of soft iron between them, the latter becomes a temporary magnet while so situated; for the end next the N. (*red*) pole of the magnet will become a S. pole, and the end next the S. (*blue*) pole of the other magnet will become a N. pole: the iron bar has now become a magnet by indnction.

But the effect is only temporary, for if we turn the iron bar gradually about its centre it will as gradually lose the magnetism acquired by induction; when it is at right angles to the two magnets it will be in a neutral condition, and if turned further it will become magnetised in the opposite way.

If a soft iron bar be presented endways to either pole of a suspended magnet it will attract, though slightly that pole; and it is indifferent which end of the iron bar is presented. In either case the pole of the magnet "induces" a pole of an opposite character in the iron bar; and between poles of opposite character, as before stated, there is always attraction.

The power of inducing magnetism in iron diminishes as the distance increases. When the inducing magnet is slowly removed the forces exerted by the ends of the iron bar undergo a corresponding diminution; and they cease to exist altogether when the magnet is wholly withdrawn, and the bar returns to its natural or neutral state. Thus the magnetism induced in iron is *temporary* only.

The foregoing facts enable us to account for the *attraction* of iron by the magnet, and to reduce the phenomenon to the general principle of the attraction of opposite, and the repulsion of similar, poles.

When the pole of a magnet is brought near to a mass of iron, the immediate effect, we have seen, is to render the latter a magnet by induction, an *opposite* magnetism being developed in the part of the mass which is *nearest* to the acting pole, and a *similar* magnetism in the part which is most *remote*. Now, as opposite poles attract one another, while similar poles repel, attraction will ensue between the acting pole and the nearer parts of the iron mass, and repulsion between the same pole and the remoter parts; and the former of these forces will preponderate, being exerted at a shorter distance. It follows from this that attraction must always result, whichever pole of the magnet be presented to the iron.

Since the magnetism which has been induced in a piece of iron imparts a similar condition to a second piece in its vicinity, and that to a third, and so on, it follows that attraction must ensue between these several pieces, although with diminished energy, as they are more distant from the acting pole; and the first will support a second, the second a third, and so on, if only the weights of the successive peices be proportionate to the diminished force. A magnetic chain can thus be formed, having two poles. The following experiment illustrates the matter:—Let a few pieces of iron rod, or a few soft iron nails be taken. If one of these (see Fig. 70) be placed in contact with the pole of a permanent steel magnet it is attracted to it and becomes a temporary magnet; it now, in turn, supports a second piece, this, in turn, a third piece, and so on, until a chain of four or five pieces is built up. Each of these pieces of iron is itself a magnet; if it be the north pole of the magnet to which the pieces are attached, the end of the first piece in contact with the steel magnet will have south, and the other end north, magnetism, and this last will develop in the nearest end of the next piece of iron south magnetism, and so on. But if the steel magnet be removed from the top of the chain all the rest drop off, and are found to be no longer magnetic.

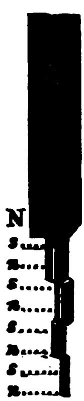

Fig. 70.
Magnetic chain.

A piece of soft iron laid with one end on the end of a magnet practically becomes part of the magnet, simply extending its length, and its further end being of the same polarity as that of the magnet to which it is joined.

When the pole of the inducing magnet is brought near to other portions of the iron bar, more complicated results follow. Thus, if the magnet be made to touch the middle of the bar (instead of the end), their longer sides being at right-angles, an opposite pole will be developed by induction at the point of contact, and similar poles at the two ends. If a circular plate of iron be laid horizontally, and a bar magnet be allowed to rest upon it vertically at its centre, the plate will acquire by induction the *opposite* polarity to that of the acting pole at its *centre*, and a *similar* polarity at every point of its circumference.

226. Attraction of Iron by a Magnet explained.—The inductive action here explained accounts for many phenomenæ, which at first sight seem at variance with the general laws of magnetic force. When the similar poles of two magnets are brought near they repel one another, while dissimilar poles in the same circumstances attract. Now the forces emanating from the two poles of the same magnet are equal, and, accordingly, the repulsion of the similar poles of the two magnets should be equal to the attraction of the dissimilar poles at the same distance. The latter force, however, is observed to be always greater than the former. This difference is explained by the effect of induction. When the *dissimilar poles* of the two magnets are presented to one another, each pole induces the opposite magnetism in the near part of the other magnet; and the magnetism so induced is *added* to that which it already possesses, and the two polar forces become *stronger* than they were when the two magnets were apart. On the other hand, when the *similar* poles of two magnets are presented to one another, the magnetism induced in each by the presence of the other is *opposite* to that which it already possesses, and the resulting polar forces are *weakened*. Hence the attraction of the dissimilar poles always exceeds the repulsion of the similar poles at the same distance.

227. Effects of Induction.—It may even happen, by the effect of induction, that the repulsion of the similar poles is converted into attraction. Thus, when the similar poles of two magnets, which are very unequal in size and power, are brought near, the opposite polarity induced in the near end of the smaller, by the action of the pole of the larger, will, at a certain distance, just balance the similar polarity which it possesses; while within that distance, the induced polarity will exceed the other, and the resulting action will become attractive. Accordingly, when the pole of a strong magnet is presented to the similar pole of a weak one at a considerable distance, repulsion will take place. As the interval between the poles is lessened, the polar force of the weaker magnet is gradually diminished, and at a certain distance there is no action. Within that distance the polar force changes sign, and the repulsion is converted into attraction.

Thus it is that two magnets of unequal strength always adhere when brought into contact by their similar poles.

In comparing the phenomena of magnetic induction with those of electrical induction we find both points of resemblance and points of difference. In the case of electricity, if the influencing and influenced body are allowed to come in contact, the former loses some of its own charge to the latter. In the case of magnetism there is no such loss; a magnet after touching soft iron is found to be as strongly magnetised as it was before.

228. Magnetisation.—The various sources of magnetism are the influence of natural or artificial magnets, terrestrial magnetism, and electricity. The three principal methods of magnetisation by the *inductive* action of permanent magnets are known by the technical names of single touch, separate touch, and double touch.

229. Method of Single Touch.—The steel bar to be magnetised is placed horizontally on a table, and one of the poles of the magnetising bar, held vertically, is brought into contact with it at one of its extremities. The magnetising bar is then to be drawn, parallel to itself, along the surface of the steel bar to the other end; after which it is to be lifted and replaced in its first position, and the operation repeated. After ten or twelve such rubbings, the steel bar is to be inverted and the same process repeated upon its other face, taking care that the same pole of the acting magnet is employed, and that it is always moved in the same direction. The end, or pole, of the steel bar at which the pole of the magnet *leaves* the bar will always be of the *opposite* magnetism to that of the magnetising magnet. That is, if the north-seeking (or *red*) end of the magnet is used the end of the steel bar last touched by it will be a *blue* or south-seeking pole.

This process will answer sufficiently well when the needle to be magnetised is of small dimensions. It cannot impart to large bars all the magnetism of which they are capable, and it has the inconvenience of generating *consecutive poles* when the bar to be magnetised is long, unless much care be taken in giving an equable motion to the moving magnet.

230. Methods of Separate or Divided Touch.—This method, which was first used by Dr. Knight in 1745, consists in placing the two opposite poles of two magnets of equal force in the middle of the bar to be magnetised, and in moving each of the magnets simultaneously towards the opposite ends of the bar. Each magnet is then placed in its original position and this operation repeated. After several frictions on both faces the bar is magnetised. In Dr. Knight's method the magnets are held vertically. M. Duhamel perfected the method by inclining the rubbing magnets at an angle of 20° with the horizon;* and the process is still more effectual if the ends of the bar are mean time supported on the opposite poles of two other equally powerful bar magnets, the poles being of the same name as those of of the two magnets used for stroking the steel bar. The relative position of the poles of the magnets is indicated in the figure.

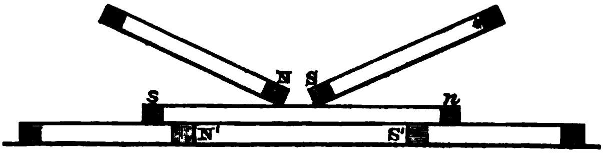

Fig. 71.—Showing Magnetism by Method of *Separate* or *Divided* Touch.

This method produces the most regular magnets.

231. Magnetisation by the action of the Earth.—That the earth operates as a magnet, and at each point of its surface the force emanating from it has a fixed direction or intensity, and, hence, that like other

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[*] It is now ascertained that a smaller inclination is more advantageous. According to Capt. Kater the maximum effect is produced when the inclination of the magnetising bars is reduced to two or three degrees.

magnets it can give both permanent and temporary magnetism is shown by many natural and artificial phenomena. The permanent magnetism of lodestone when its deposits are in the magnetic meridian is an example of one kind, and the magnetism in the soft iron of a dynamo-electric machine is an example of the other. All soft or cast iron rods or bars, or other elongated forms of cast or soft iron, unless the position of their length is at a right-angle to the line of the direction of the earth's magnetic force, are immediately rendered magnetic by induction from the earth, and the nearer the iron is to the line of force or dip the greater will be the amount of induction. When a bar of soft iron is held on the magnetic meridian and parallel to the dip it becomes immediately endowed with feeble magnetic polarity. The lower extremity is a N. (*red*) pole, and if the N. (*red*) pole of a small magnetic needle be approached to it it will be repelled. If the bar be held vertically the lower end will still be a north pole, but of less intensity. If the bar is held horizontally north and south the north end will be a north pole but of still lesser intensity, the south end a south pole also of lesser intensity. If we now turn the bar in the same horizontal plane its magnetism will diminish, and if placed in an east and west direction it will lose its polarity, and if we turn it still further, until its position is reversed, the magnetic poles of the bar will be reversed.

Magnetism resulting from induction may be more or less permanent, or totally transient. Thus it has been found that a bar of iron that has remained fixed for a long period in a direction parallel, or nearly so, to the earth's line of force becomes a permanent magnet. If, however, the bar be of hardened steel its magnetism will require a little time to arrive at its *maximum* intensity of magnetisation, because of its coercive force causing it for a short time to resist magnetisation.

Since the effect of inducing action is much increased by mechanical concussion, or any other cause which imparts molecular vibration to the bar while under the action of the inducing force, hence, to magnetise an iron bar we have only to hold it in the direction of the earth's magnetic force, and to strike it on the end while so held with a hammer. The bar will be found to acquire by this simple process a considerable amount of magnetism. As the direction of the earth's magnetic force in the higher latitudes is not far from the vertical the effect produced will be nearly the same if the bar be held vertically. The end of the bar which was lowest being charged with north (*red*) magnetism; and this magnetism is not transient like the induced magnetism of soft iron, changing its place in the bar with every change in the position of the bar, but is constant like that of a steel bar, retaining the same magnetism whatever the position of the bar. By reversing the position of the bar and striking it a few blows with the hammer, its magnetism is reversed. The magnetism of the bar so struck resembles that of a steel magnet in all respects but this, that while, perhaps no change can be remarked in hours or days, it infallibly diminishes in a long time. To express this partially permanent character the term *Subpermanent Magnetism* has been adopted.

232. Magnetisation by the Electric Current.—Much greater power can, however, be obtained by means of electro-magnetism; and the two following methods are now almost exclusively employed by the makers of magnets.

A fixed electro-magnet (Fig. 72) is employed, and the bar to be magnetised is drawn in opposite directions over its two poles. Each stroke tends to develop at the end of the bar at which the motion ceases the opposite magnetism to that of the pole which is in contact with it. Hence strokes in opposite directions over the two contrary poles tend to magnetise the bar the same way.

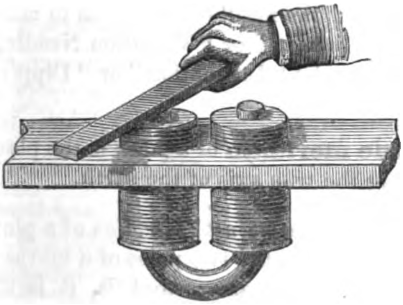

Fig. 72.—Method of Magnetisation by an Electro-Magnet.

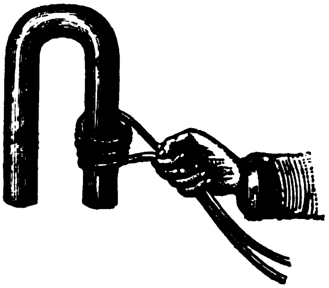

Fig. 73.—Method of Magnetisation by an Electric Current.

When very intense magnetisation is to be produced the electro-magnet must be very powerful, and the bar then adheres to it so strongly that the operation above described becomes difficult of execution, besides scratching the bar. Hence it is more convenient to move along the bar, as in Fig. 73, a coil of wire through which a current is passing. This was the method employed by Arago and Ampere.

233. Destruction of Magnetism.—The capability of induction, and the correlative power of retaining the induced magnetism, as we have seen, are both greatly affected by any mechanical or other force which excites a vibratory motion in the particles of the iron. On the other hand, the magnetism of a steel bar is weakened, or even wholly destroyed by the same means; the vibratory motion which is imparted to the molecules of the body favouring the recombination of the separated magnetism, and, therefore, the return of the body to the neutral state. It is thus that the power of a magnet is seriously lessened, or altogether destroyed, by a fall from a height upon a hard pavement.

234. The terrestrial magnetic force is determined both in direction and magnitude, when we know the position of the vertical plane containing the direction of the force; the angle which that direction makes with the horizon, and the number which expresses the intensity of the force itself, referred to some known unit. In addition to these we have to consider the distribution of its effects over the surface of the globe, and the changes it is subject to. The distribution will be noticed under the heads of its direction and intensity, being represented in each case by a system of imaginary lines on the earth's surface, the change will be noticed subsequently.

235. I. The Direction of the Force of Terrestrial Magnetism.—This is estimated in two co-ordinate planes, the one horizontal, the other vertical, in the former of which the geographical meridian is taken as the initial line. It is measured by the direction of the magnetic needle suspended to move in each of these planes: the needle hung so as to move in the horizontal plane is called the "Declination" or "Variation Needle," that hung so as to move in the vertical plane, the "Inclination" or "Dipping Needle."

236. The geographical or **true meridian** of a place is the plane passing through the place and containing the true axis of the earth.

237. The Magnetic Meridian.—The *magnetic meridian* of a place is the vertical plane passing at this place through the two poles of a movable magnetic needle in equilibrium about a vertical axis; that is, it is the vertical plane in which a magnetised needle tends to place itself.

The magnetic north is not any one point, *i.e.*, the magnetic meridians at different parts of the earth's surface do not cut any one point as the true meridians do. The forms of the magnetic meridians are very remarkable. None of them appear to be exactly a great circle. They converge to a north pole, north of Hudson's Bay, and a south pole in South Victoria; but these poles are not opposite. From long. 70° E. to 150° E. the northern parts agree nearly with the geographical meridians; the same remarks also applies to a large portion of the southern part for long. 150°.

238. The Direction in the Horizontal Plane.—Magnetic Declination, or Variation.*—In general the magnetic meridian does not coincide with the geographical meridian, and the angle which the magnetic makes with the geographical meridian, or which is the same thing, the angle which the direction of the needle makes with the meridian is called the *declination* or *variation* of the magnetic needle. The declination is said to be *east* if the north pole of the needle points east of the true or geographical meridian; but the declination is *west* if the north pole of the needle points west of the true meridian. It is very different at different places, and at a given place undergoes a gradual change from year to year, besides smaller changes backwards and forwards which are continually taking place.

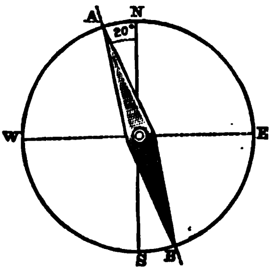

Fig. 74.—Declination.

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* Magnetic Variation is the term still employed by nautical men, but for which, among men of science, the term Magnetic Declination is usually substituted.

The following table gives particulars of the Declination, Inclination (Dip), and total magnetic force at a number of important places, the values being approximately true for the year 1880.

Table of Magnetic Declination and Inclination for Year 1880.

Places.	Declination.	Inclination.	Polar Force. C.G.S. Units.
Boothia Felix	None	90° 0′ N.	·65
London	18° 40′ W.	67 40 N.	·47
St. Petersburg	0 40 W.	70 0 N.	·48
Berlin	11 30 W.	64 0 N.	·48
Paris	16 45 W.	66 0 N.	·47
Rome	11 30 W.	60 0 N.	·45
New York	7 57 W.	72 12 N.	·61
Mexico	7 55 E.	?45 0 N.	·48
Quito	7 40 E.	?25 0 N.	·35
St. Helena	26 25 W.	28 0 S.	·31
Cape Town..................	30 2 W.	56 30 S.	·36
Sydney	9 30 E.	62 45 S.	·57
Hobarton	8 49 E.	71 5 S.	·64
Tokeo	4 5 W.	50 0 N.	·45

239. Lines of No Variation, or Agonic Lines.—In certain parts of the earth the magnetic coincides with the geographical meridian. Imaginary lines passing through all these points where the needle points due North or South are called *Lines of No Variation, or Agonic Lines.*

240. Isogonic Lines, or Lines of Equal Variation.—Lines connecting all points where the needle is deflected from the geographical meridian by an equal quantity are called *Lines of Equal Variation, or Isogonic Lines.* These are extremely irregular curves, and form two closed systems, surrounding two points which may be called *Centres of Variation.* One of these points is in Eastern Siberia, the other in the Pacific Ocean, in the vicinity of the Marquessa.

If we imagine the earth to be covered with perfectly similar declination needles without influence upon one another, we shall find certain of them having no declination; the line joining all such needles is called an *agonic* line.

Confining our attention for the present to the actual configuration of the *lines of no variation*, we find that there are two principal *lines of no variation.* Of these the western traverses the continent of America and the Atlantic Ocean, in a direction from north-west to south-east. Commencing in the Polar Sea, about Port Kennedy, say in about lat. 75° N., and long. 100° W., its course has been traced through Hudson's Bay and Lake Ontario, until it leaves the North American continent near Cape Hatteras, in about 75° W. long. It then traverses a portion of the Atlantic Ocean to the eastward of the West India Islands, until it meets the continent of South America near the mouth of the River Amazon, in about long. 50° W. Proceeding thence, in a south-easterly direction, it cuts the shores of the continent again near to Rio Janeiro, between 40° and 45° W. long., and enters the South Atlantic, where it pursues the same direction as before, and can be traced towards the S. pole as far as 60° S. The course of this line presents but little inflection, and is inclined to the meridian nearly at the same angle throughout.

The eastern line of no declination follows, for the most part, a similar direction. It traverses European Russia from the White Sea to the Caspian, and enters the Arabian Sea in about 65° E. It then pursues the same general direction in the Indian Ocean, as far as 8° S. lat., from 90° to 120° E. long. To the eastward of this it bends again southward, intersects the north coast of Australia in about 125° E. long., and finally emerges, and enters the great Australian bight, in about long. 130° E.

In the space between these two lines—to the east of the former and west of the latter—the declination is *westerly*. This space includes the eastern part of America, the Atlantic Ocean, nearly the whole of Europe, and the whole of Africa. In the remaining division of the globe—to the west of the former, and to the east of the latter—including the Pacific Ocean, and the greater part of Asia and America, the variation is for the most part *easterly*. There is, however, in the eastern part of Asia and the adjoining sea a *closed curve of no variation*, within which the declination is again *westerly*. This remarkable loop, inclosing part of Siberia and of the Chinese Empire, has the form of an oval, whose greater axis lies nearly in the meridian of 130° E. long. The diameter of the oval extends from about 20° to 70° N. lat., and long. 105° to 150° E., inclosing, therefore, Japan and part of China, Manchouria, and Siberia. It is almost certain that there is a similar but smaller loop agonic line just south of the equator, and between 120° and 130° W.

The point of the equator at which the westerly declination is greatest is in the Atlantic Ocean, to the south of the Bight of Benin, nearly in the meridian of Greenwich. There are two points of greatest easterly declination, with an intervening minimum. These three points are all in the Pacific Ocean.

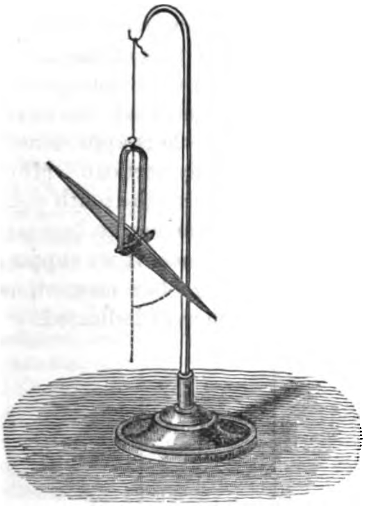
If we, in like manner,, follow the line of needles which have all, say, 5° W. declination (variation) we pursue an *isogonic* line; this runs nearly parallel with the agonic. But the greater the angle of declination on the isogenic, the more does it depart from parallelism with the agonic; and this, whether the declination is east or west, until the isogonics cease to cross the equator. These agonic and isogonic lines are continually shifting slightly through the day and seasons, and altering through the centuries.

The lines of equal declination, although of great use to the navigator, are ill adapted to carry a distinct view of the phenomena in themselves, or to exhibit their physical relations. The most natural, as well as the most instructive modes of grouping graphically the observed results, seems to be that adopted by DUPERREY in the charts published in 1836. The curves of DUPERREY indicate—not the deviation of the needle from the true north at each place—but its *actual direction*. The magnetic meridian in this case are curves traced on the globe, to which the direction of the freely suspended horizontal needle is everywhere a tangent. At each point, therefore, the direction of the curve is that of the magnetic meridian of the place. These meridians converge towards two points, one in the northern and the other in the southern hemisphere. They do not, however, all meet in the same point; but the successive intersections of each pair of contiguous meridians form a closed curve, the central points of which may be denominated *magnetic poles*. The north magnetic pole, so defined, is nearly in lat. 70° N., long. 98° W.; that of the south magnetic pole is to the south of Australia in lat. 75° S., long. 138° E.

DUPERREY has traced on the globe a series of curves which are in every point normal to the preceding, or at right-angles to the direction of the freely suspended horizontal needle. These curves he denominates *magnetic parallels*. They serve, even more directly than the preceding, to point out the relations between the declination (variation) and the other magnetic elements. The magnetic parallel which denotes equally from the terrestrial equator on both sides, or that for which the sum of the latitudes = 0, may be denominated the *magnetic equator*. The mean plane of this curve is inclined to the terrestrial equator at an angle of 11°. Its ascending node is near the western coast of Africa, in about 10° E. long., measured from the meridian of Paris. Its descending node is in the Pacific Ocean, in about 170° W. long.

241. The Direction in the Vertical Plane.—Inclination, or Dip.—If, before magnetising a needle, we mount it on an axis passing

Fig. 75.



through its centre of gravity, and support the ends of the axis, as in Fig. 75, by a thread, the needle will remain in equilibrium in any position in which it may be placed. If it be then magnetised and suspended by its centre of gravity, and be free to assume any direction, it will no longer be indifferent, but will place itself in a particular vertical plane called the *magnetic* meridian, and will take a particular direction in that plane. This direction is not horizontal, but inclined generally at a considerable angle to the horizon. The axis of the magnet lying in the direction of the line of force, and the angle which this axis makes with the horizontal plane is the Dip, or Inclination.

Def.—The angle included between a horizontal plane and the axis of a magnetic needle when allowed to come freely to a state of rest (*i.e.*, when the vertical plane in which it moves coincides with the magnetic meridian) is called the *Dip*, or *Inclination;* and a line through the poles of the needle at that time is called the *Line of Force.*

242. Magnetic Poles.—At two points, or rather linear spaces on the earth's surface, the needle assumes a position perpendicular to the horizon, or the dip is 90°. These two spots are called *magnetic poles.* At the North magnetic pole, the North (*red*) pole of the needle dips; at the South magnetic pole, the South (*blue*) pole of the needle dips. The terrestrial magnetic poles do not coincide with the geographical ones, nor are those points diametrically opposite. The positions of these poles are lat. 70° N., long. 97° W., and lat. 70° S., long. 102° E.

243. Magnetic Equator, or Aclinic Line, is the line which joins all those places on the earth where there is no dip; that is, all those in which the dipping needle is quite horizontal. This line which is not a great circle, does not coincide with the terrestrial equator, which it crosses in two points, and never recedes from it on either side further than 12°; the position of the two being nearly coincident in that part of the Pacific where there are few islands, and most divergent when traversing the African and American continents.

It will be seen that the increase of dip is nearly double of the increase of latitude; and upon this circumstance was founded the conjectural law

Tang. dip = 2 tang. distance from magnetic equator.

244. Magnetic character of the Earth and a Magnet, their analogy.—A striking analogy exists between the character of the earth and that of an artificial magnet. Having provided a little unspun silk, by means of a bit of wax, or otherwise, attach the silk fibre to the magnetic needle. Place a bar magnet on the table and hold the needle over the equator (X, Fig. 76) of the magnet. The needle sets horizontal, or comes to rest in a position of parallelism to the bar, with its S. pole pointing to the N. pole of the bar, and its N. pole pointing to the south pole of the bar—being acted on equally at its opposite ends by equal forces of attraction and repulsion. Move the needle towards the north end of the magnet, the south end of the needle dips, the dip augmenting as the north pole is approached, over which the needle, if free to move, will set itself exactly vertical. Move it back to the centre, it resumes horizontality; pass it towards the south pole, its north end now dips, and directly over the south pole the needle becomes vertical, its north end being now turned downward. Hence, if we suppose a series of small magnets to be suspended above a large bar magnet, as shown in Fig. 76, they assume the respective positions therein indicated.

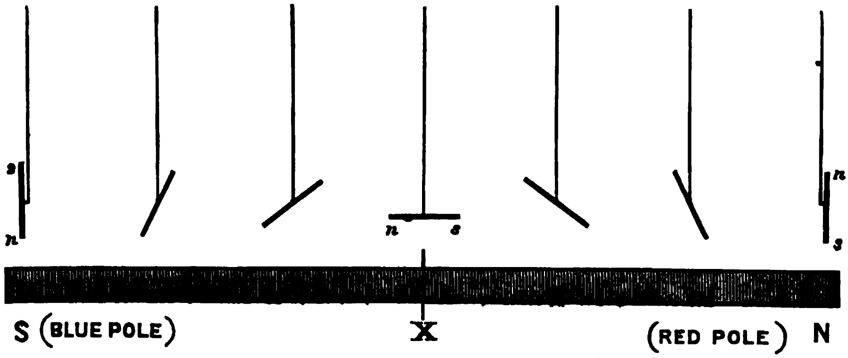
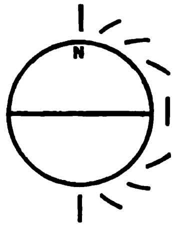


Fig. 76.—Showing action of a Powerful Magnetic Bar on a series of Small Magnets suspended by threads. N S and *n s*, North and South Poles; X, Neutral Line, or Magnetic Equator.

Thus we learn that on one side of the magnetic equator the north end of the needle dips, on the other side the south end dips, the dip varying from nothing to ninety degrees.

Imagine now that this bar magnet represents a portion of the earth's surface extending along a given magnetic meridian between the magnetic pole of the northern hemisphere, and that of the southern hemisphere, and we have an exact image of the way in which a needle freely suspended from its centre of gravity is acted upon when carried from pole to pole (Fig. 77). If we go to the equatorial regions with a suitably suspended needle we shall find the position of the needle horizontal. If we sail north the N.-seeking end (*red* pole) of the needle dips, and if we sail south the opposite end (*blue* pole) of the needle dips, and over the north magnetic pole, the N.-seeking end (or *red* pole) of the needle points as nearly as can be measured, vertically downwards; similarly at the magnetic pole of the southern hemisphere the needle again stands vertically, but with the S.-seeking end (or *blue* pole) downwards. At the magnetic pole a declination needle is, of course, at rest in any position.

Fig. 77.



245. Isoclinic Lines, or Lines of Equal Dip.—Lines connecting places in which the dipping needle makes the same angles with the horizon are called *Lines of Equal Inclination, or Dip*, also *Isoclinic Lines.*

The results of the observations of the magnetic inclination, made in different parts of the earth, were first graphically represented by Wilcke, who first published a chart of the lines of equal inclination (dip) in the Memoirs of the Academy of Stockholm, in the year 1768. A second and greatly improved chart of the isoclinical lines was constructed by Hansteen, for the epoch 1780. The most recent map of these lines is that constructed by General Sabine, and published in the second edition of Johnston's Physical Atlas. These lines, in their general configuration, resemble closely the magnetic parallels referred to. Within the tropics they are slightly inclined to the equator; the flexures increase with the latitude, and in the higher latitudes they tend to form closed curves, encompassing the points at which the inclination is 90°, or the needle assumes the vertical position. Near to the Magnetic Poles the curves are oval, or rather pear shaped; but the major axis of the northern curves and those of the southern curves are not in the same direction. It is to these points that the name of *Magnetic Poles* is ordinarily given. It has been already mentioned that Halley and Hansteen inferred the existence of *four magnetic poles* from the configuration of the lines of equal declination in the higher latitudes. According to Hansteen, the same conclusion is confirmed by the form of the isoclinical line, and he concludes that there are four points on the earth's surface at which the dip needle assumes the vertical position. It has been pointed out, however, by Gauss, that the existence of two points in the same hemisphere, for which the inclination is 90°, necessarily involves the existence of a third between them. The position of the north magnetic pole has been exactly fixed by Sir James Ross, who reached the spot itself in his arctic journey in 1831. It is situated in Boothia Felix, in lat. 70° 5′ N. and long. 96° 46′ W. The south magnetic pole lies to the south of Australia, and upon the Antarctic Continent discovered by the same intrepid navigator. It is situated, according to Duperrey, in 75° S. and 138° E.

Encircling the earth is *the line of no dip* on every part of which the needle remains horizontal. Much labour has been bestowed upon the determination of the position of this line, which is called the *Magnetic Equator*. It cuts the terrestrial equator to the south of the Bight of Benin, in long. 5° 40′ E. The curve thence ascends rapidly and reaches its greatest latitude in the interior of Africa, in about long. 40° E. It thence descends very slowly towards the equator, in its progress eastward, cuts the eastern coast of Africa, near Cape Guardafui, traverses the Indian Ocean in a direction nearly parallel to the terrestrial equator, crosses the Peninsula of India a little to the north of Cape Comorin, crosses the Peninsula of Siam, touches the Island of Borneo at its northernmost point, and finally reaches the equator in the middle of the Pacific Ocean, in about long. 173° W. The eastern and western nodes of the magnetic equator are therefore very nearly antipodal. The curve thence descends to the south of the equator, to which it is nearly parallel through 40° of long., viz., from 110° to 150° W., after which it descends more rapidly and traversing the South American continent, reaches its highest southern latitude, close to the eastern shore, in about long. 40° W. From this point it ascends rapidly until it cuts the equator in the point from which it sets out.

It has been already said that the eastern node of the magnetic equator is in the Atlantic Ocean, in 5° 40′ E. The position of the western node is less determinate, for the two equators are nearly coincident through a space of nearly eighteen degrees from 178° E. long. to 164° W. long. If we take the middle of this space as the western node its position is 173° W. long. The greatest distance of this curve from the equator is in 57° E. long., its amount is 11° 40′. Its maximum of southern latitude is 15° 40′, it occurs in the interior of the South American continent, in about 48° W. long. Its mean plane makes with the equator an angle of 10° 40′.

It will be observed that the course of the curve does not differ materially from the principal normal to the magnetic meridian, to which, as already stated, the title of *true* *magnetic meridian* has been given; its course is, however, somewhat less regular. The irregularities of the former line, and of the magnetic curves generally, are ascribed by DUPERREY to these which occur in the distribution of temperature, and are caused by the distribution of land and water in the earth's surface.

246. Intensity of the Force of Terrestrial Magnetism.—If a magnetic needle be moved from its position of equilibrium it will revert to it after a series of oscillations which follow laws analogous to those of the pendulum. If the magnet be removed to another place and caused to oscillate during the same length of time as the first, a different number of oscillations will be observed. And the intensity of the earth's magnetism at the two places will be respectively proportional to the squares of the number of oscillations.

If at M the number of oscillations in a minute had been $25 = n$, and at another place, M′, $24 = n'$, we should have

$$\frac{\text{Intensity of the earth's magnetism at M}}{\text{Intensity of the earth's magnetism at M}'} = \frac{n^2}{n'^2} = \frac{625}{575} = 1{\cdot}085.$$

That is, if the intensity of the magnet at the second place be taken as unity that of the first is 1·085. If the magnetic condition of the needle had not changed in the interval between the two observations this method would give the relation between the intensities at the two places.

247. Foci of Maximum Intensity.—There are four points on the surface of the earth where the magnetic force is a maximum, two in each hemisphere; that of the greatest and that of the least intensity lying in the southern hemisphere. These points are called the *Foci of Maximum Intensity.* The northern foci lie the one in Hudson's Bay and the other in Siberia; the southern foci, one in the South Atlantic and the other in the South Pacific.

248. Dynamic Equator.—An irregular curve encircling the earth is drawn through that point in each meridian on which the magnetic intensity is least, this is called the *Dynamic Equator.*

The *Magnetic Equator*, which is "the line of no dip," is not that which is of real practical importance, especially to navigators, but the *Dynamic Equator*, which has reference to the *intensity* of the magnetic force. It is this curve which is the true line of demarcation between the northern and southern magnetic hemisphere, separating the opposite phenomena of the diurnal changes, and dividing the forces which attract the north end of the needle from those which attract the south end.

The force is of unequal intensity in its several parts. This equator separates the forces which attract the north end of a magnetic needle from those which attract the south end, and is the true line of separation between the northern and southern magnetic hemispheres.

249. Lines of Equal Magnetic Intensity, or Isodynamic Lines.—Intermediate to the foci and Dynamic Equator are lines passing through all the points where the magnetic intensity is the same, these are called *Lines of Equal Magnetic Intensity, or Isodynamic Lines.* In each hemisphere they first form a series of ovals round each of the foci there situated, having their major axis in the line joining the two foci. At a greater sweep a pair of these ovals join and form a figure ∞, and exterior to this single curves encompass both foci. These are first much inflected towards the point of juncture, but become more regular as they approach the Dynamic Equator.

The lines of equal horizontal force approximate also to the parallels of latitude, but not so nearly as those of equal dip.

The greatest horizontal force is near the Equator, as should be the case even if the total force were everywhere constant, since as the dip decreases the horizontal component of the force must increase.

The magnetic force increases, generally, in proceeding from the tropics northward and southward, and attains a maximum value at two points, or *foci*, in each hemisphere, of unequal intensity.

In the northern hemisphere the position of the stronger focus has been very exactly determined by General Lefroy. It is situated in British America, in lat. 52° 19′ N., long. 92° W. The place of the weaker or Siberean focus, as deduced from the observations of Erman, is situated in lat. 59° 44′ N., long. 118° E. The ratio of the forces at the two *foci* is that of 1°·07 to 1°. The weaker focus appears to have changed its place very considerably since the investigations of Halley, so far as its position may be inferred from the isogonic lines, while that of the stronger pole has varied little.

The two southern *foci* are much nearer to one another. Their positions, as deduced from the observations of Sir James Ross in his Antarctic voyage are, the stronger in lat. 64° S., long. 138° E., and the weaker in nearly the same latitude, and in long. 125° W. The interval of longitude is accordingly less than 100°. The positions of the principal poles of force in both hemispheres are different for the points of 90° inclination, and are more distant from the terrestrial poles. The isodynamic lines as they approach these *foci*, form closed curves. The observations in the southern hemisphere are not as yet sufficient to separate the curves which encompass the two *foci*.

The line of *weakest force* on the globe has been traced with great care by General Sabine. It is an irregular line, lying for the most part to the south of the terrestrial equator. It reaches its maximum of northern latitude in the Pacific Ocean, in about 165° E., long., where it attains the latitude of 14° N. Its southern limit lies in the Atlantic Ocean, in about 20° W. long., where it touches the tropic of Capricorn. It is not a line of equal intensity; on the contrary, it intersects the weaker isodynamic lines, which appear to form loops, in two points, one in the Atlantic and the other in the Pacific Ocean.

The least intensity observed by Humboldt was on a point in the magnetic equator, in latitude 7° 2′ S., and longitude 81° 8′ W., from Paris. The magnetic equator was then supposed to be the locus of *least intensity*, and also an *isodynamic* line; and it was accordingly inferred that the intensity thus observed was an *absolute minimum*. Humboldt accordingly referred all the other intensities observed by him to this, as the unit; and in this practice he has been followed by other observers. We now know, chiefly by the labours of General Sabine, that none of these assumptions are true; that the line of least intensity does *not* coincide with the magnetic equator, and that neither of these lines is an *isodynamic* line. Hence the unit of force thus adopted is purely arbitrary. The intensity of the force at Paris, referred to the unit, is 1·348. The comparison of the forces at London and Paris was made by Sabine, with great care, in 1827. The force in London thus inferred is 1·372. The forces at other places, which have been compared by observation with either Paris or London, are by means of these numbers reduced to the same unit. The intensity of the stronger magnetic focus has been found by General Lefroy to be 1·88; that of the weaker, as determined by Hansteen and Erman, as 1·75. The intensities of the two southern foci, as determined by Sir James Ross, are 2·06 and 1·96 respectively.

The Admiralty (England) have published charts by Capt. Evans, F.R.S., showing the magnetic elements. They are constructed on Mercator's principle, and a line is drawn at intervals of one degree through all places having the same variation. On another Mercator's chart lines are drawn through places having the same dip or inclination. On a third chart lines are drawn through places which have the same magnetic intensity.

250. Terrestrial magnetism is influenced by causes which render its phenomena subject to variation and changes affecting both its direction and intensity. There are *Secular Variations* which take centuries to run their course, and the causes of which are as yet unknown. There are also *Periodic Variations* which run through their course in ascertained periods, and which can be traced to their causes. Again, there is the *Horary* or *Diurnal Variation*, which, like the tides, goes through the changes twice in the twenty-four hours. Once more, there are *Transient Perturbations.*

251. Variations in Declination.—The declination of the magnetic needle, which, as already mentioned, varies in different places, is at present west in Europe and in Africa, but east in Asia and in the greater part of North and South America.

252. Secular Variation.—In the same place the declination varies in the course of time, and the needle appears to make oscillations to the east and west of the meridian, the duration of which is several centuries. The following Table exhibits the character and rate of this change at London, where the declination has been observed at intervals since the latter part of the sixteenth century.

Table of Secular Magnetic Variations.

Year.	Declination.	Inclination.
1576	......	71° 50′
1580	11° 17′ E.	......
1600	......	72 0
1622	6 12	......
1634	4 0	......
1657	0 0 min.	......
1676	3 0 W.	73 30
1705	9 0	......
1720	13 0	74 42 max.
1760	19 30	......
1780	......	72 8
1800	24 6	70 35
1816	24 30 max.	......
1830	24 2	69 3
1855	23 0	......
1868	20 33	68 2
1878	19 14	67 43
1880	18 40	67 40
1888	17 40	67 25?

Thus we see that the declination was easterly at London from 1580 to 1657, at which latter epoch it vanished, and the magnetic meridian coincided with the astronomical. After the year 1660, the declination became westerly, and attained its maximum westerly value, viz., 24° 27′, in London in the year 1815, or soon after. Since that time westerly declination has been diminishing, and the magnetic meridian been approaching the astronomical in the opposite direction, though so slowly that it would be rash to predict when, or even if, 0 will be reached. It diminishes in England at about the rate of 7′ per year, and should this continue the needle will again point true north, making a complete cycle of change in about 320 years.

Similar phenomena have been observed at Paris. These observations show distinctly an easterly maximum in or about the year 1580. The epoch of no declination at Paris was the year 1669. That of the westerly maximum was in the year 1814.

It appears, according to the Table of Secular Magnetic Variation above, that the *Inclination* in 1576 was 71° 50′, and it slowly increased till 1720, when the angle of dip reached the maximum value of 74° 42′. It has since steadily diminished to its present value of 67° 39′. The period in which the cycle is completed is not known, but the rate of variation of the dip is less at the present time than it was fifty years ago. In all parts of the earth both declination and inclination are changing similarly. The foregoing table gives the data of the secular changes at London.

The following table, extracted from that given by General Sabine in the first volume of the Cape Observations, exhibits the nature of the secular change at that station from a very remote period.

Secular Changes of Declination at the Cape of Good Hope.

Year.	Declination.	Year.	Declination.
1605	0° 30′ E.	1753	19° 0′ W.
1609	0 12 W.	1768	19 30
1622	2 0	1780	22 16
1675	8 14	1792	24 31
1691	11 0	1818	26 31
1724	16 23	1836	28 38

From the foregoing observations it appears that the north end of the needle has moved at the Cape towards the west from the time of the earliest observation. The rate is nearly uniform, the annual amount of the secular change being 7′ 56″. The magnetic meridian coincided with the astronomical in or about the year 1607.

253. Daily Variations.—Besides this (secular) change there is a daily variation in declination, of such a nature that the needle in the twenty-four hours passes twice through its mean position. Commencing shortly after midnight the N.-seeking pole moves to the East; at about a quarter past seven it is about 6′ or 7′ from its mean. It then travels back again and passes the mean magnetic meridian at about ten o'clock. Still travelling westward, at about one o'clock it reaches its extreme daily westerly excursion, which may be as much as 3° from the mean. It then begins to move eastward; it passes the mean at about five or six in the afternoon, and continues slowly till about ten or eleven, probably really all night; but between ten or eleven at night and one or two in the morning the motion is insensible. The first morning movement is in the same direction as the last sensible evening motion. Thus the westerly declination is greater during the warmer part of the day.

Further, having eliminated the secular and diurnal variations of declination, there is said to be another following the seasons, and which may be called a solsticial variation. The data are at present somewhat insufficient and, indeed, contradictory. The balance of evidence seems to show that there is an excess of declination in the months from September to March inclusive, and a defect from April to August inclusive; and that this is the case in both hemispheres.

254. In the southern hemisphere the *south* end (*blue* pole) of the needle dips; and the inclination has increased from the time of the earliest observations. The following are the observations of south inclination made at the Cape of Good Hope since the middle of the last century.

Secular Changes of the Inclination at the Cape of Good Hope.

Year.	Inclination.	Observer.
1751	43° 0′	La Caille.
1770	44 25	Ekeberg.
1780	46 46	Bailey.
1791	48 30	Vancouver.
1818	50 47	Freceynet.
1836	52 35	Fitzroy.
1840	53 8	Ross.

255. Diurnal Variation in Dip.—The dip is also subject to slight annual and diurnal variation, being, according to Hansteen, about 5′ greater in summer than in winter, and 4′ or 5′ greater before noon than after. Taking a whole year and the mean dip at half-past twelve, which is the time of minimum, the dip at eight is 1′·6 greater. Hence it diminishes, with some fluctuations, at about 9 P.M., till midnight. But the hourly maxima are different for different months, thus:—

In	January the maximum is at		9	A.M.	In	July the maximum is at		8	A.M.
,,	February	,,	7	,,	,,	August	,,	7	,,
,,	March	,,	7	,,	,,	September	,,	6	,,
,,	April	,,	7	,,	,,	October	,,	6	,,
,,	May	,,	9	,,	,,	November	,,	5	,,
,,	June	,,	9	,,	,,	December	,,	8	,,

256. Intensity.—The foci of magnetic intensity, with their systems of curves, are moving along the two hemispheres in different directions, those in the northern hemisphere going from west to east, those in the southern from east to west; and as the foci move with different velocities, the forms, as well as the position of the curves, are continually changing.

In the British Islands the total force is greatest in June and least in February; but in the southern hemisphere, in Tasmania, the reverse is the case.

257. Eleven-Year Period.—General Sabine discovered that there is a larger amount of variation of the declination occurring about once every eleven years. Schwabe noticed that the recurrence of these periods coincided with the eleven-year periods at which there is a maximum of *spots* on the sun. Prof. Balfour, Stewart, and others have endeavoured to trace a similar periodicity in the recurrence of **auroræ** and of other phenomena.

258. Magnetic Storms.—But over and above all regular and periodic changes there is a large amount of irregular fluctuation, which occasionally becomes so great as to constitute what is called a *magnetic storm.* Magnetic storms "are not connected with thunder storms, or any other known disturbance of the atmosphere; but they are invariably connected with exhibitions of aurora borealis, and with spontaneous galvanic currents in the ordinary telegraph wires; and this connection is found to be so certain, that upon remarking the display of one of the three classes of phenomena we can at once assert that the other two are observable (the aurora borealis sometimes not visible here, but certainly visible in a more northern latitude)."* They are sensibly the same at stations miles apart, for example, at Greenwich and Kew, and they affect the direction and amount of horizontal much more than vertical force.

The phenomenon of earth currents appears to be connected with that of the changes in the earth's magnetism, and can be observed whenever there is a display of aurora, and during a magnetic storm; but it is not yet determined whether these currents are due to the variation in the magnetism of the earth, or whether these variations are due to the currents. It is known that the evaporation always going on in the tropics causes the ascending currents of heated air to be electrified positively relatively to the earth. These air-currents travel northward and southward toward the polar region where they descend. These streams of electrified air will act like true electric currents, and as the earth rotates within them it will be acted upon magnetically. Whether this will account for the gradual growth of the earth's magnetism is an open question. The action of the sun and moon in raising tides in the atmosphere might also account for the variations mentioned. It is important to note that in all magnetic storms the intensity of the perturbations is greatest in the regions nearest the poles; also that the magnetic poles coincide very nearly with the regions of greatest cold; that the region where the auroræ are seen in greatest abundance is a region lying nearly symmetrically round the magnetic pole.

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* Airy on *Magnetism*, page 204.

DEVIATION OF THE COMPASS.

259. One of the most practical, as also one of the most useful, purposes to which the laws explained in the preceding chapters of this work can be applied, is to find the effects of the iron used in the construction of ships on the compasses placed in them; and the reader who thoroughly understands these laws will have no difficulty in deducing the results which follow.

260. The iron of which a ship is constructed is neither wholly hard nor wholly soft, but of an intermediate character; and the more nearly it approximates to hard the more capable it is of the retention of magnetism when it has been subjected to any process of magnetisation. In an iron ship intense magnetism is developed by the bending, twisting, and hammering to which the iron is subjected; N. (*red*) magnetism being developed in the part of a ship which is below and towards the north, and S. (*blue*) magnetism in the part which is above and towards the south; and so far as the hull is concerned it is of that kind which is now called sub-permanent, because it has not the precise consistency of a steel bar magnet.

261. In the northern hemisphere all vertical or upright bars, such as stanchions and angle-irons composing the frames of ships, are magnetised by induction, the lower ends being north (*red*) poles, the upper ends south (*blue*) poles, the upper end attracting the north pole of the needle held near them. On the other hand, in the southern hemisphere, these conditions are reversed; the upper ends of vertical iron are north poles, repelling the north pole of a compass needle and attracting the south pole. On the magnetic equator, where there is no dip, vertical soft iron has no polarity, because its position is at right-angles to the earth's line of force or dip. It is different with horizontal pieces of soft iron; they exert the same influence on a compass needle in both hemispheres, and in all latitudes.

The hull of an iron ship acts as a permanent magnet on compasses placed outside the vessel as well as those placed inside; an iron ship must therefore be viewed in its effect on a properly placed magnet rather as one great magnet, than as an aggregation of smaller magnets.

Keeping in view that the inductive effect from the earth's magnetism is greatest in the line of the dip, and the existence of a neutral equatorial plane at right-angles to the line of dip in spherical bodies, we are prepared to see that each iron ship must have a distinct distribution of magnetism depending on the place of building, and the direction of the head and keel while building; the ship's polar axis and equatorial plane conforming more or less to the line of dip of the earth at the place where built, and a plane at right-angles to that line; abundant observation and experiment have proved this important general principle.

262. To illustrate this principle: let us suppose, as in the following Figs. 77, 78, 79, and 80, that four iron ships, or four composite-built ships, with ribs, beams, stanchions, and deck girders of iron, are building on the cardinal points of the compass, in a port in England where the line of the earth's total magnetic force is inclined 70° to the earth's horizontal magnetic force, or in other words, where the dip of the needle is 70°.

Fig. 77 shows the magnetic state of a ship built head North magnetic. The line marked Dip passes through the centre of the ship; it shows the direction of the line of the earth's magnetic force. The line marked Equatorial or Neutral line is the line of no deviation, and runs at right-angles to the Dip. The after body of the ship, or the portion which is shaded, has S. (*blue*) polarity, and the fore body, or white portion of the figure, N. (*red*) polarity; the upper part of the stern would have the S. (*blue*) polarity developed in a high degree; the lower part of the bows would have the N. (*red*) polarity equally developed. At the stern the north end of a compass needle would be strongly attracted; at the bow the south end of the needle would be strongly attracted; while a compass placed outside of the ship's topsides, above the line of no deviation, the north end of the needle will be attracted; if it be placed below that line the north end of the needle will be repelled and the south end attracted, in accordance with the law of magnetism.

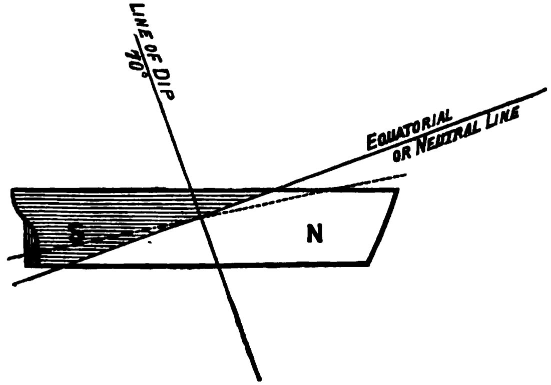

Fig. 77. Head North while building.

Fig. 78 represents the magnetic condition of a ship built head south. It will be seen by comparing Fig. 78 with Fig. 77 that the conditions are reversed; in Fig. 77 the magnetism of the after body of the ship is south (*blue*), while in Fig. 78 the after part of the ship possesses north (*red*) polarity; now the fore body of the ship has S. (*blue*) polarity, while in Fig. 77 it has N. (*red*) polarity; the upper part of the bow has S. (*blue*) polarity developed in a high degree, and the lower part of the stern N. (*red*) polarity equally developed. The N. (*red*) polarity of the stern repels the north end of the compass needle, and the S. (*blue*) polarity of the bow attracts it. The dotted line crossing the equatorial line in Figs. 77 and 78 shows the probable position of the neutral line after the ship has been sometime afloat, with her head in an opposite direction to that in which she was built, or after she had made a voyage.

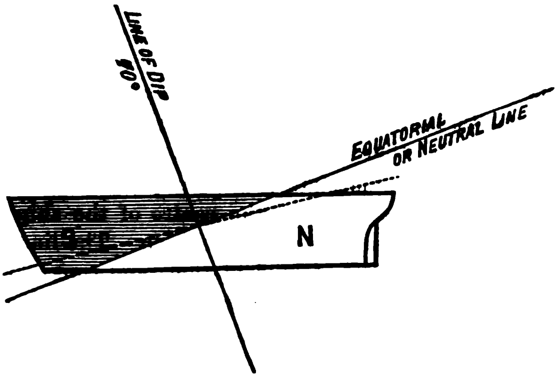

Fig. 78. Head South while building.

The place of little or no deviation in a ship built head north is towards the bow, but in a ship built head south, towards the stern.

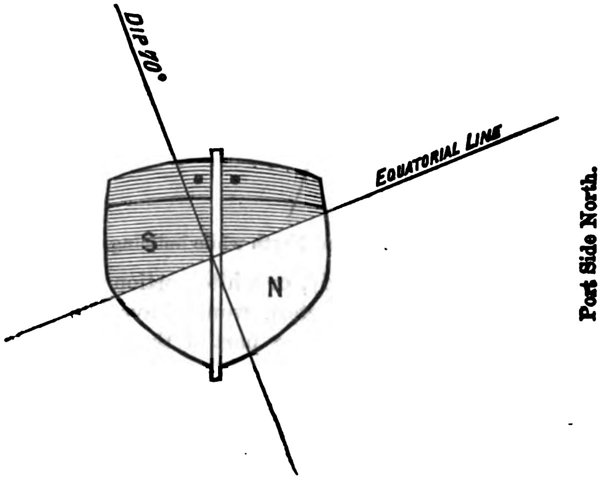

Fig. 79. Head East while building.

Fig. 79 is intended to show the magnetic state of a ship built head East. The whole of the upper part of the ship has S. (*blue*) polarity; the whole of the lower part has N. (*red*) polarity; but the S. (*blue*) polarity predominates on the starboard side, and the north end of a compass needle, if carried at the usual height of a compass along the amidship line of the upper deck from end to end, is attracted to the starboard side.

In Fig. 80, ship built head West, the magnetic conditions of Fig. 79, head East, are reversed; the whole of the upper part of the ship has still S. (*blue*) polarity, and the lower N. (*red*) polarity; but the magnetism of the port side of the upper works is developed in a higher degree than the starboard side, and the N. end of a compass needle, if carried along the upper deck from end to end, would be attracted to the port side. In other words, in these

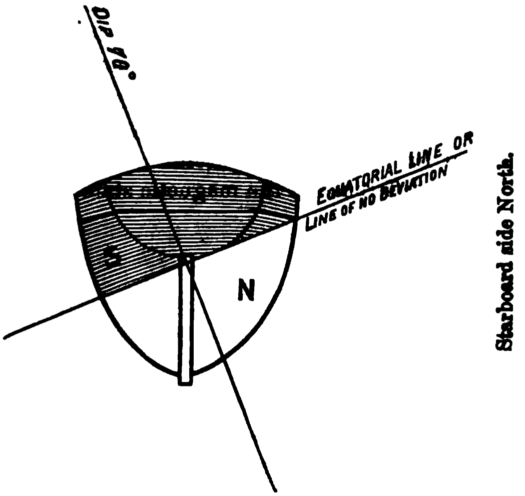

Fig. 80. Head West while building.

ships the whole of their decks have a S. (*blue*) polarity, yet in that part which was North while the ship was being built, this S. (*blue*) polarity is developed in a less degree than on the opposite side, consequently the N. point of the compass is drawn towards that part of the ship in which the S. (*blue*) polarity is developed in the highest degree.

Theoretically, there should be no spot of no deviation on the deck of ships built East or West.*

This disposition of magnetism, and its results as here described, appertain to the northern hemisphere.

The diminution of the directive force is greater if the ship has been built East and West than if built North and South; also the deviation is less symmetrical, regular, and permanent than those of a ship built North and South.

The equatorial or neutral line rising to the deck forward in ships built head North, and aft in ships built head South, might lead to the supposition that a compass placed in one or the other position would not be effected by the magnetism of the ship; it is well to place a compass aft in ships built head South, and as far forward as possible head North. But the line or

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* From the special magnetic properties developed in a ship according to her position when building, it follows that a compass *aft*, in the usual place of the steering binnacle, the *character* of the deviation—*though not the amount*—may be approximately represented in a tabular form, as follows:—

Approximate magnetic direction of ship's head while building.	Approximate easterly deviation occurs when ship's head by compass is near	Maximum westerly deviation when ship's head by compass is near
N.	W.	E.
N.E.	N.W.	S.E.
E.	N.	S.
S.E.	N.E.	S.W.
S.	E.	W.
S.W.	S.E.	N.W.
W.	S.	N.
N.W.	S.W.	N.E.

space along which the magnetism of the ship has no influence on the compass is not easily discovered, and if it were ascertained for any given latitude it would be found to have changed on reaching another magnetic latitude.*

Fig. 81 represents an iron ship built head North in Australia, with a dip of about 68° South. In this ship the shaded part showing S. polarity lies below the equatorial line. It will be useful to compare this figure with Fig. 77, and mark the difference in the magnetic state of the two ships.

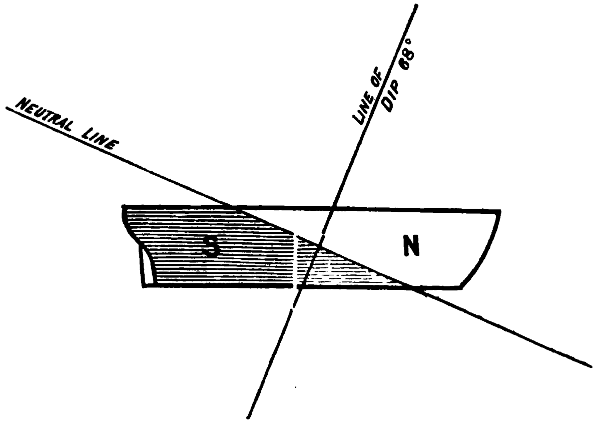

Fig. 81. Head North at Australia.

A little attention to the above diagrams will give the seaman a rough idea of the distribution of magnetism in iron ships; but it must be borne in mind that all large *detached* pieces of iron in a ship, such as iron masts, funnels, cylinders, and other masses of vertical iron, are independent magnets; in north magnetic latitude, their lower ends being north poles, their upper ends south poles.

The compasses of composite ships with iron frames and iron deck beams, are affected in the same way as those of ships built wholly of iron.

263. The errors of the compass may be classed under the heads Variation, Deviation, or Local Attraction.

264. Variation is the angle included between a magnetic and terrestrial meridian. This error arises from the magnetic poles not being coincident with geographical ones, and is due entirely to the influence of the earth on magnetic needles (see pages 75 and 96).

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* There is a very common error prevalent respecting the best position on the ship's deck for a compass. Some of the earliest writers lay it down as an axiom that on the deck of all iron ships there is a neutral point which should be sought out for the fixing of a compass. That an apparently neutral point does frequently exist is admitted. But this very point is most frequently a very dangerous position for fixing a compass. It is neutral only while the ship is in one locality. For example, in the S.S. "Fidelia," in Table Bay, just before the saloon skylight, there was no deviation. "There existed sub-permanent magnetism B = + 34°, and induced magnetism in vertical iron B = — 34°, and the resultant of these two errors was therefore zero. But had she returned to Sunderland the B = — 34° would have been changed to B = + 51°, which, when compounded with the results of sub-permanent magnetism, would have produced a horizontal force exceeding that of the earth's."

265. Deviation is the angle by which the needle is deflected from the magnetic north by the action of the iron of a ship; that is, the angle included between the magnetic meridian and a plane passing through the poles of a compass needle.

The deviation is named East or West according as the north point of the compass so disturbed is to the east or west of its natural position.

266. Local Attraction is the error caused by some disturbing force unconnected with the ship itself, or cargo, but belonging entirely to the locality, such as iron cranes, mooring posts or chains, an iron vessel near, &c.; or volcanic or other magnetic bodies like those found in Elba, St. Helena, &c.

Deviation is distinguishable from the other two errors by its depending, both for amount and direction, on the position of the ship's head and the angle at which the ship is heeled; whilst the other two are independent of the action of the ship.

267. How Compasses act in Iron Ships.—In the case of iron ships, as in that of iron bars (page 322), percussion and vibration, by hammering in rivetting, render the iron of which the vessel is constructed more susceptible to the inductive force of the earth, and causes the magnetism, which the iron of the ship thus acquires, to partake more of the character of permanent magnetism. Still this magnetism, after launching, undergoes a considerable diminution by being submitted to percussion, with the ship's head in a different position to that in which it was when she was being built, and especially if in a contrary direction. But the iron of which a ship is constructed always retains a large amount of this magnetism as long as it remains in the form of a ship, and for this reason, as, also, to distinguish it from the permanent magnetism of steel magnets, it has received the name of *sub-permanent* magnetism. The deviation arising from sub-permanent magnetism is greater than that which is the result of transient induced magnetism. The polarity of the ship's magnetism, while she remains on the stocks, takes the direction of the earth's line of force or dip, and its effects on compasses will evidently depend on the direction the ship's head was whilst being built. Taking the case of a ship built head north (Fig. 77, page 337), the fore part of the ship has acquired north (*red*) magnetism, and its action will be precisely the same as that of the north pole of a magnet; hence, on northerly courses, the north end of the compass needle will be repelled, and the directive power of the needle will be diminished. On southerly courses the north end of the needle points towards the stern, which has acquired sub-permanent south magnetism, then the directive power of the needle is increased. On easterly and westerly courses the effects on the compass are greatest, since the force acts at right angles to the needle; and on all intermediate positions of the ship's head the disturbances due to such positions are intermediate. As the ship's head is brought east of north, repulsion of the north end of the needle takes place, and westerly deviation is the result, and it reaches its maximum value when the fore-and-aft line of the ship is at right-angles to the needle; beyond that position the fore part of the ship attracts the south end of the needle, and westerly deviation is still the result. This attraction continues until the ship's head reaches south, when the line of action of the ship lies in the same direction as the needle, and no disturbance occurs, but the directive power of the needle is greater. On bringing the ship's head round west of south, the south pole of the needle still continues to be attracted, which causes easterly deviation, and it again attains its maximum when the fore-and-aft line of the ship is at right-angles to the disturbed needle; this must occur to the north of west. After that point has been reached by the ship's head, the fore part of the ship repels the north end of the needle, easterly deviation still being the result until the ship's head is again at north. Thus we find that in an iron ship as her head is moved in azimuth round an entire circle the disturbance of the compass is little or nothing when her head is on or near the points to which her head or stern were directed while building, and that between these two points are two semicircles, in one of which the deviation is westerly, and in the other easterly, and is greatest, or *maximum*, in each case when the ship's head is directed to the points of the compass that were abeam while on the building slip, *i.e.*, occuring at that point where the disturbing force is perpendicular to the direction of the deflected needle; and, moreover, for the intermediate parts or points of the semicircle the deviation will be proportional to the *sine* of the azimuth of the ship's head, reckoned from the point of *no* deviation in the direction of the maximum. Or, again, to put it in another way, supposing the observer to be standing in the centre of the compass *looking towards* the direction of the ship's head when building, the semicircle to the right of him would have westerly, and that to the left easterly, deviation. The deviation caused by sub-permanent magnetism acquired in building, and the effects of magnetism induced in vertical iron, has received the name of **Semicircular Deviation,** from producing opposite effects when the ship's head is on opposite semicircles of the compass, as the ship's head moves round a complete circle of azimuth. The part due to sub-permanent magnetism remains the same in kind, though different in amount, in all latitudes and longitudes, unless the ship be subjected to strains or other mechanical violence. The part caused by the magnetism induced in vertical iron changes with a change of geographical position, or, more correctly, as the dip changes, and is of contrary names on opposite sides of the magnetic equator, that is, if westerly deviation be produced on one side, easterly will be produced on the other. At the magnetic equator the earth's magnetism acts horizontally, and vertical soft iron will have no magnetism, and the semicircular deviation arising therefrom will disappear.

268. Theoretical Representation of the Semicircular Deviation.—If we place a magnet before the compass with its S. end (*blue* pole) turned to the compass it will draw the N. end (*red* pole) of the needle to the ship's head, and as the ship is turned round there will be, in the first or eastern semicircle, a deviation of the north point of the compass to the right hand or east; in the second or western semicircle, a deviation to the left hand or west. This would produce one part of what is called the "semicircular" deviation.

If we place a soft iron rod vertically in front of the compass, with its upper end at the level of the compass, this end which will be S. (*blue* pole), will attract the north end of the needle, and produce a deviation of exactly the same kind as the magnet we have described above as having its *blue* pole pointing to the compass. It will, therefore, simply increase the semicircular deviation caused by the magnet.

If the N. end (*red* pole) of the magnet, or the lower end of the rod be nearest the compass—or if the magnet or rod be abaft the compass, an effect of the same kind, but in an opposite direction, will be produced.

A magnet to starboard or port of the compass will produce a similar effect to that already described, except that a deviation of one kind will be produced when the ship's head is in the northern semicircle, and of the other kind when in the southern semicircle. This is the other part of the "semicircular" deviation.

The effect of the two magnets and the one iron rod, which we have considered make up the whole of what is called the semicircular deviation.

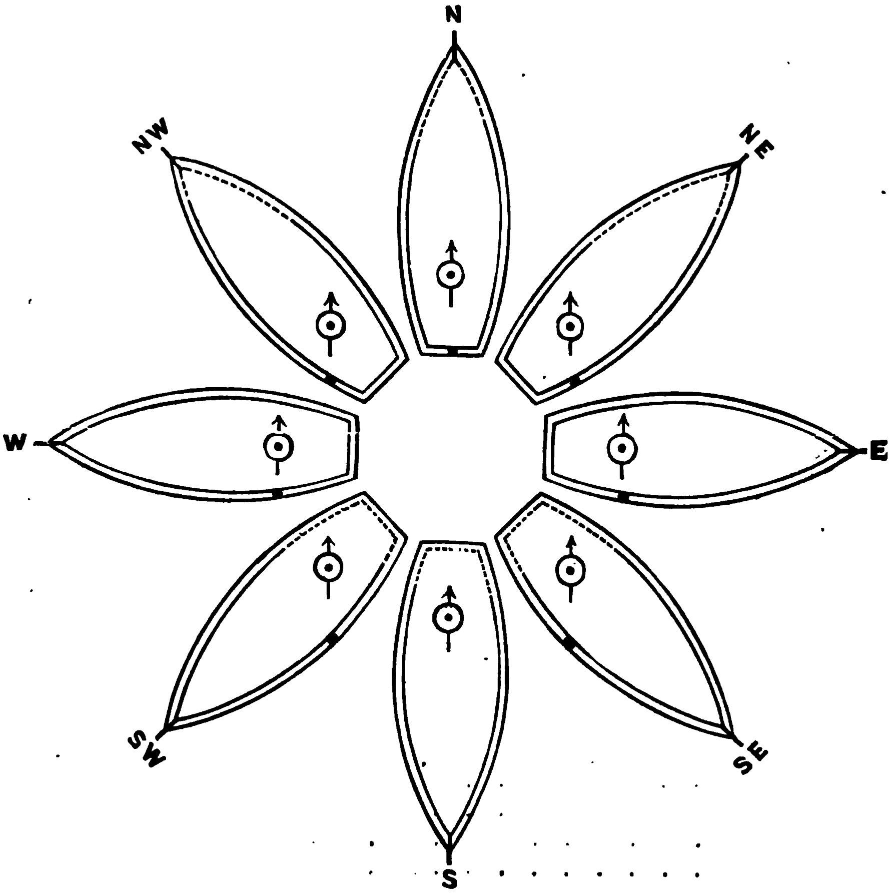
269. As a general rule the magnetism producing semicircular deviation, in a ship built in north magnetic latitude, attracts the north end of a compass needle to that part of a ship which was south from the compass while building; hence, the semicircular deviation in iron ships is generally represented by the effect of a magnet at that part of the ship which was south in building, with its south end towards the compass. Thus, in a ship built head north, the north end of the needle is drawn towards the stern. The following table will show the part of a ship towards which the north end of a needle is generally drawn, that is, the position of the permanent south pole developed in the process of construction.

Ship's head while building.	The north end of the compass needle on the poop or quarter deck is usually drawn.
North	towards the stern.
N.E.	,, starboard quarter.
East	,, starboard side.
S.E.	,, starboard bow.
South	,, bows or right ahead.
S.W.	,, port bow.
West	,, port side.
N.W.	,, port quarter.

The position in the ship from which the polar force may be considered as emanating may be illustrated by the following figure, representing eight iron ships built respectively on the eight principal points of the compass. Keeping in view the principle referred to in a former paragraph, that the N. end of the compass needle *is attracted to that part of the ship which was south from the compass while building*, we observed of the figures of the ships the position of the permanent south pole developed in the process of construction marked thus ●.

In the ship built head north it will be seen that the N. end of the compass needle is drawn to a point on the stern immediately in a fore-and-aft line; in the ship head N.E., to a point on the starboard quarter making an angle of 45°

Fig. 82.

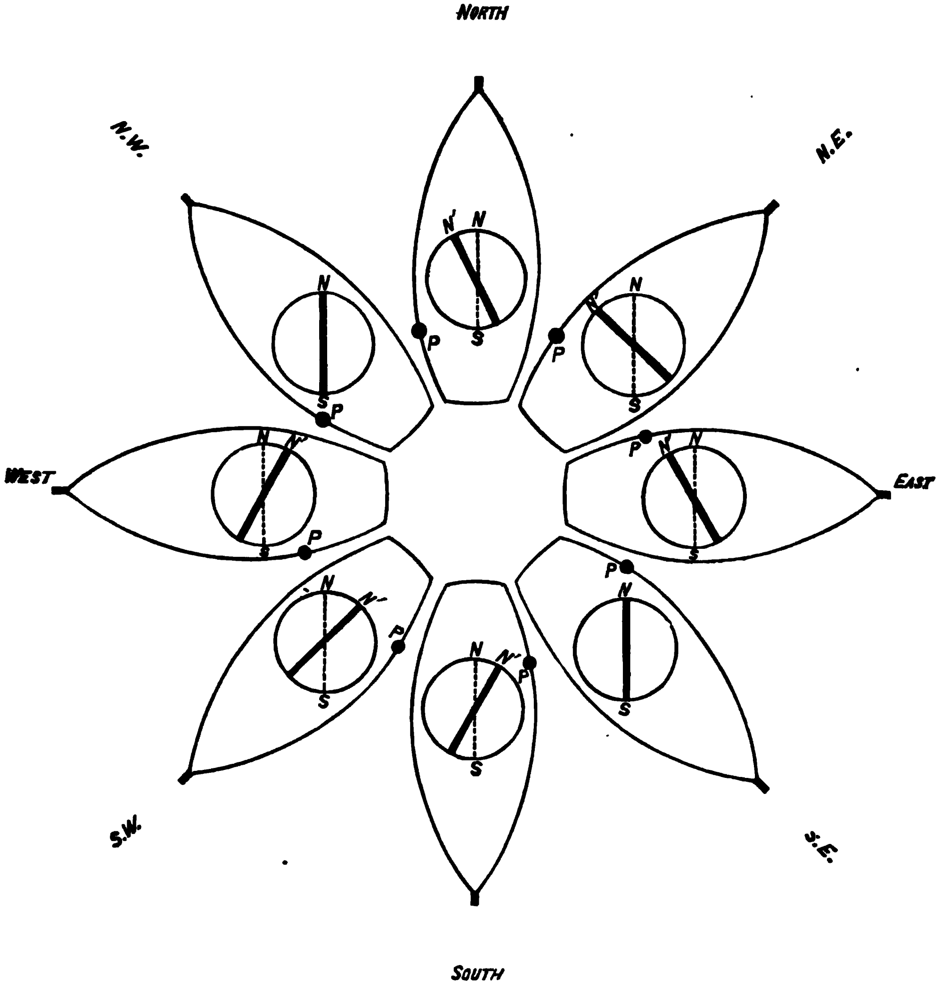


from the fore-and-aft line; in the ship head East, to a point on the starboard side abeam of the compass; in the ship head S.E., to a point on the starboard bow at an angle of 45° from the fore-and-aft line; in the ship head south, to a point in the bow immediately in a fore-and-aft line; and so on for the several remaining directions.

Fig. 83 will further illustrate the way in which the permanent magnetism and the inductive magnetism of vertical iron acts upon the compass to produce semicircular deviation. Let it be supposed that the whole of the south polarity or attractive power of the above magnetism is concentrated in the point P on the port quarter of a ship built with her head near N.W. The ship is supposed to be swung round the compass, beginning at the N.W. point. The small circles represent the compass, the thick lines N′S the compass needle, the dotted lines the magnetic meridian or the direction of the needle

Fig. 83.

Magnetic.



when free from deviation. Beginning at N.W., and noting the position of the point P, it will be observed that there can be no semicircular deviation with ship's head in that direction, because the attractive force of the ship's magnetism at the point P is in a line with the compass needle N S. As the ship's head swings round towards the west, the relative positions of the point P and the compass needle will alter, and P will exert a pulling force upon the north end of the needle, causing it to deviate to the right from N to N', shown in the figure at West. The easterly deviation will increase until the ship's head swings to S.W., where it attains its greatest or maximum amount. After passing S.W. it gradually decreases past South until the ship's head reaches S.E., the opposite direction to that in which her head was built, where it is again zero or nothing. The point P is now on the opposite side of the compass to what it was when her head was at N.W., but it will be observed that it is in a line with the needle, and can exert no deviating influence over it.

As the ship swings with her head towards the East, the needle will gradually be drawn to the left hand, until the westerly deviation attains its maximum at N.E. After passing N.E. the westerly deviation will decrease past North until the ship's head again reaches N.W., at which point there is no deviation. A very slight inspection of the figure will show that in the semicircle from N.W. round by the West to S.E. the deviation is easterly; while in the semicircle, or half the compass, from S.E. round by the East, the deviation is westerly. The above is merely given for the sake of illustration, but it must be remembered that no two ships are alike in their influence on the compass, nor will the ship's magnetism have the same effect on two compasses placed on different parts of the deck.

270. A soft iron mass and horizontal soft iron exert a wholly different influence on the compass from that hitherto described.

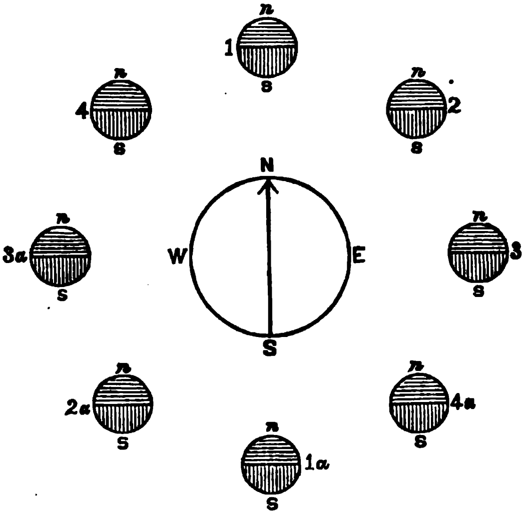
The effect of a soft iron ball on the needle when carried round the compass in the same horizontal plane is illustrated as follows (Fig. 84):—*

At 1 the spherical ball of soft iron lies in the magnetic meridian, and North of the compass; it therefore, according to the law of like poles repelling and unlike poles attracting, produces no deviation, but the directive force of the needle is increased.

At 2 the sphere lies in the N.E. quadrant, and consequently, since the attraction is to the right, it produces E. deviation in that quadrant, and the directive force of the needle is increased.

At 3 the sphere lies East of the compass, and at right-angles to the deviation of the needle, where it produces no deviation, but still increases the directive force.

Fig. 84.



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* A Treatise on Magnetism, by Sir G. B. Airy.

At 4 the sphere lies in the N.W. quadrant, and since the attraction is towards the left, it therefore produces W. deviation in that quadrant, and the directive force of the needle is increased.

With the sphere lying at 1^a, 2^a, 3^a, and 4^a, the effect on the compass will be similar to that of the respective positions 1, 2, 3, and 4; that is, producing no deviation at South and West, easterly deviation in the S.W. quadrant, and westerly deviation in the S.E. quadrant.

From the preceding remarks it is evident that—

Soft iron in the horizontal plane of the compass invariably increases the directive force of the magnetic needle.

Soft iron in the horizontal plane of the compass gives *no* deviation at the four cardinal points, N., E., S., and W., by compass; but the other position in each of the four quadrants are affected as follows:—if the iron lies in a direction—

between N. and E. it produces Easterly deviation.
„ E. „ S. „ Westerly „
„ S. „ W. „ Easterly „
„ W. „ N. „ Westerly „

Two soft iron masses on opposite sides of the compass, and in the same plane, affect the needle to the extent of their mass and force.

Two masses situated at right-angles with each other increases the directive force to the extent of their sum, and produce a deviation equivalent to the difference, of their forces.

271. How the action of a horizontal bar of soft iron revolving round the compass differs from that of a magnet. —If a bar of soft iron is held in the direction of the dip it becomes a magnet, the upper end of which, in North latitude, attracts the N. end of the magnet, if it is moved into a horizontal position, but still pointing North and South it is still magnetic, under the influence of the horizontal component of the earth's force, though in a smaller degree. If it is now moved horizontally in an East and West direction, its magnetism still further diminishes, and when it reaches the East and West position its magnetism disappears altogether. (See No. 231, page 321).

If, therefore, a compass is acted upon by this bar or horizontal rod of soft iron when directed towards the needle, and lying before or abaft it, the phenomenon is wholly different* from that arising from the action of a magnet bar, because, as we have just seen, the magnetism of the rod is not constant, but varies with the azimuth of the rod from the north. When, therefore, the bar is North or South of the needle, it attracts it strongly, but as the needle is already pointing North, its directive force is increased, but its direction is not disturbed; if the rod is carried radially, say to the East, the needle is drawn toward it and so has an Easterly deviation, which is a *maximum* when it is a little past N.E.

But the bar as it approaches the E. and W. position loses its magnetism; and when E. and W. has none, and therefore does not attract the needle, and produces *no* deviation; consequently, the deviation will be zero when the bar is N. and S. and N. of the compass, zero when the bar is E. and W. and E. of the compass, and will have a maximum, as just stated, somewhere between N. and E.

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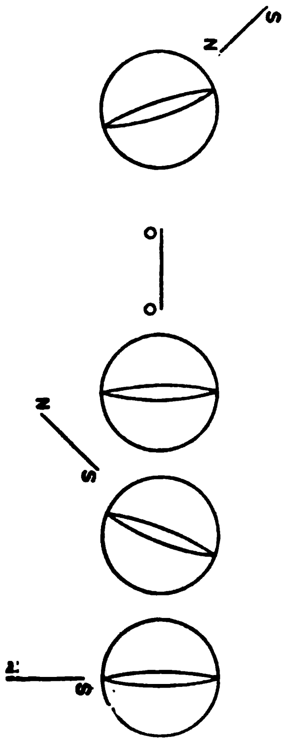
* "The law of disturbance may be represented (for memory only) by this rule: the mass (or rod) attracts that pole of the needle which is nearest to it."—AIRY, *A Treatise on Magnetism*, page 138.

It will be the same in each quadrant, except that in the second quadrant, E. to S., the S. end of the needle will be attracted by the N. end of the bar, thus giving a W. deviation. E. in the S. to W. quadrant and W. again in the W. to N. quadrant (see Fig. 85). It thus changes in each quadrant, and produces a deviation of the kind called quadrantal.

Fig. 85.



The top of the page represents the N.

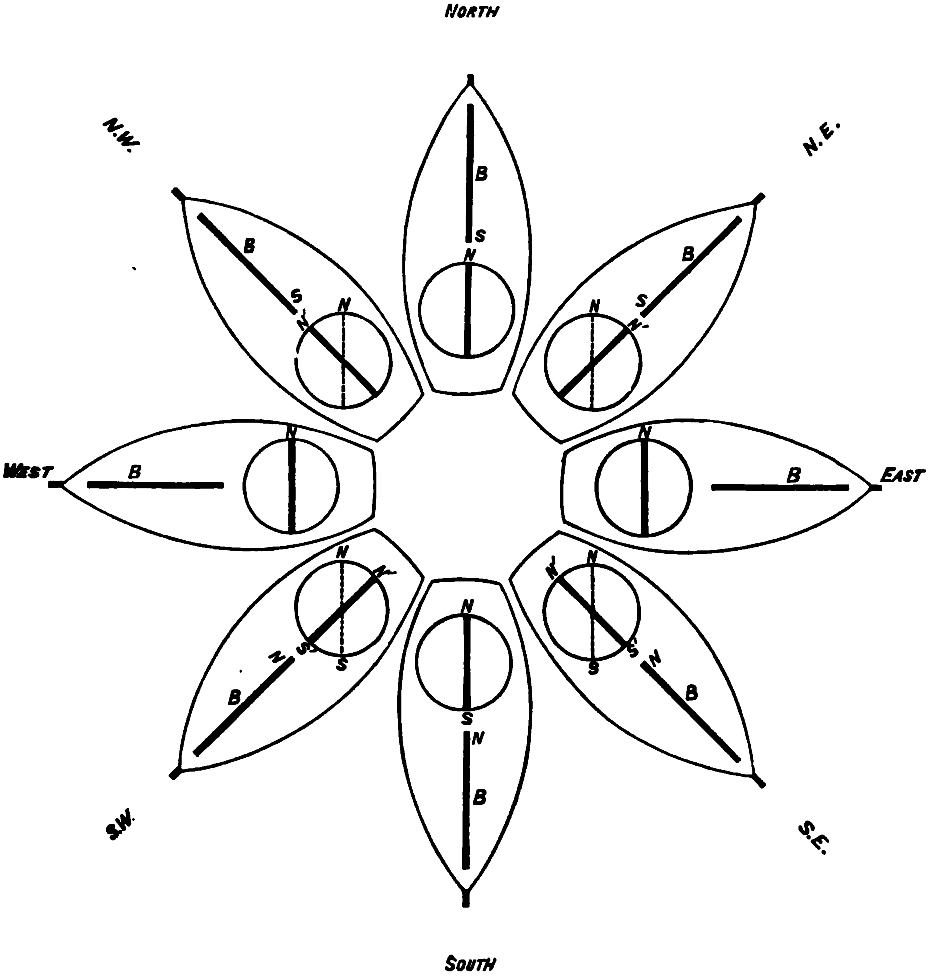
272. Quadrantal Deviation is so named from its being easterly and westerly, alternately, in the four quadrants as the ship moves round a complete circle of azimuth. It is caused by the transient or inductive magnetism of horizontal soft iron, which in an iron ship is not alone the horizontal soft iron *near* the compass that produces it, but all connected with the hull, the keel, frame and fittings running fore-and-aft, athwartships, diagonally, over, under, and in the plane of the compass; in addition to which, in a steamer, there are the engines, screw shaft, &c. It is zero or nothing when a ship's head is near the North, South, East, or West points, and greatest on the quadrantal points. It is generally easterly in the N.E. and S.W. quadrants, and westerly in the N.W. and S.E. quadrants of the compass.

This quadrantal deviation is divided into two parts, one, which is the more important, and which has its maxima at or near the intercardinal points N.E., S.E., S.W., N.W., and the other, which has its maxima at the cardinal points N., S., E., and W., and which is generally so small that it may be neglected. It arises from soft iron unsymmetrically distributed.

To illustrate the way in which horizontal soft iron produces quadrantal deviation, let us suppose the whole of the induced magnetism in a ship to be

Fig. 86.

Magnetic.



represented by the soft iron bar B in Fig. 86. This cannot be so in actual practice, because the athwartship horizontal iron produces quadrantal deviation as well as the fore-and-aft iron, but we may suppose it may for the sake of clearness. The small circles represent the compass, the thick lines within the small circles the compass needle, the dotted lines within the compass the magnetic meridian. Beginning at north, it will be observed that the bar B is parallel with the magnetic meridian, and will therefore be an inductive magnet while it is in or near that position, its after end, marked S., being a south pole; but as the bar B is in a line with the compass needle N, it cannot exert any deviating power upon the needle, either to the right or left. As the ship's head swings towards the N.W., the relative positions of the bar B and the needle N are altered, and the south end of the bar draws the north end of the needle to the left from N to N′. As the ship's head approaches the west, the bar B loses its polarity, and at west it is at right-angles to the magnetic meridian, and ceases to exert any influence on the compass. The ship's head now swings towards the S.W., and the bar B, as it turns towards the south pole, again becomes an inductive magnet; its after end being a *north pole*, and drawing the south end of the compass needle from S to S′. When the ship's head reaches south there is no quadrantal deviation, because the bar B is in a line with the compass needle. As her head swings towards the S.E., the needle is drawn from S to S′, causing westerly deviation. At east there is no deviation, for the same reason that there was none at west. After passing east, the after end of the bar B becomes a *south pole*, and draws the north end of the needle to the right-hand in the N.E. quadrant. As the ship's head approaches the north, the quadrantal deviation gradually decreases until it becomes nothing at north. The reader will observe that the bar B in this case produces easterly deviation in the N.E. and S.W. quadrants, and westerly deviation in the N.W. and S.E. quadrants. Cases may arise where the deviation is westerly in the N.E. and S.W. quadrants, but they are very rare.

273. Constant Deviation.—The "constant" part of the deviation is (unless the compass be improperly placed), in all cases in which observations have been carefully made with good instruments, small in amount, and it probably more often arises from index or other instrumental error, or from error in the assumed direction of the magnetic north than from the action of the iron in the ship.

274. The quadrantal deviation, besides the remarkable uniformity in its zero points and in its direction in the several quadrants, has the further remarkable property, as before stated, of remaining unchanged in all magnetic latitudes, and of being little changed by the lapse of time.

275. The semicircular deviation differs from the quadrantal and the constant deviations in those respects. In all ships the semicircular deviation changes with a change of geographical latitude. In iron-built ships the semicircular deviation consists of two parts—one, the induced part which is generally the smaller, and varying (approximately) as the tangent of the dip; the other having its zero point when the ship's head or stern is on or near the point on which the ship's head was when building, and varying (approximately) inversely as the earth's horizontal force at the place. It will, therefore, diminish as we approach the line of greatest horizontal force, which does not differ much from the magnetic equator, and increase as we leave it on either side. If the two parts varied exactly, and not merely approximately, according to these laws, we might, by observations made in two different latitudes, discriminate the two parts, and might predict the changes the deviations would undergo in different latitudes.

TO FORM A TABLE OF DEVIATION.

276. To Make a Table of Deviations.—There are several methods in use for forming a table of deviations. When the ship's head is brought to each point of the compass in succession this is called *swinging her*, and care must be taken to see that she is beyond all magnetic influence from surrounding objects, and that the vessel herself is equipped for sea.

277. When in port there are two principal methods in general use for finding the deviation, viz.:—Method I, **by the known correct magnetic bearing of a distant object,** and Method II, **by reciprocal simultaneous bearings,** *i.e.*, with a compass on board and a compass on shore.

278. Method I.—**By the known bearing of a distant object.**—The requisite warps being prepared, the ship is to be gradually swung round so as to bring her head successively upon each of the 32 points of the Standard Compass; and when the ship and the compass card are perfectly steady, and her head exactly on any one point, the direct bearing of some well-defined object is to be observed with the Standard Compass, and registered. The ship's head is to be gently warped round in the same manner to the next point, and when duly stopped and steadied there, the bearing of the same object is to be again set, and again recorded; and so on, point after point, till the exact bearing of the one object has been ascertained with the ship's head on every separate point of the compass.

279. The object selected for this purpose should be at such a distance that the diameter of the space through which the ship revolves shall make no sensible difference in its real bearing, and should not exceed the one-hundredth part of the distance of the object. The distance must depend on the range the ship takes when swinging; if she be at anchor, in a tide-way, from 6 to 8 miles is not too much; brought up by the middle (in a dock) 2 miles will suffice.

280. The next step is to determine the *correct magnetic* bearing of the selected object from the ship; or, in other words, the compass bearing it would have from on board if it were not disturbed by the attraction of the iron in the ship. This is effected by taking the compass to some place on shore (avoiding local influence) from which the part of the ship where the compass stood and the object of which the bearings had been observed shall be in one with the observer's eye, or else in the exactly opposite direction. The bearing of the object from that spot will evidently be the *correct* magnetic bearing from the ship by the compass. The difference between the *correct* magnetic bearing of the object and the successive bearings which were observed with the compass on board, when the ship's head was on the several points, will show the error of each of these points which was caused by the ship's iron; or, in other words, the Deviation of the Standard Compass according to the direction in which the ship's head was placed.

(b) The **correct magnetic bearing** of the distant object will be the mean value of all the observed bearings, if observed on equidistant points; or of four or more compass bearings, if taken, also, on equidistant compass points.

281. II.—By reciprocal bearings.—Should there be no suitable object visible from the ship, and at the requisite distance as stated above, the deviations must be ascertained by the process of reciprocal bearings. A second compass is placed on shore where it will be entirely beyond the influence of iron of any description, and where it can be distinctly seen from the Standard Compass on board. Then take, simultaneously (known by pre-concerted signal), the bearing from each other of the compass on shore and the compass in the binnacle, as the ship is warped round so as to bring her head successively upon each of the thirty-two points of the Standard Compass on board, or on each alternate point.

To ensure the success of this operation, the compass on shore should not be more distant from the ship than is consistent with the most distinct visibility with the naked eye, of both compasses from each other. The observations should be made as strictly simultaneous as possible, the time at which each bearing is taken being noted both on shore and on board. It will be found convenient in practice for the shore observer to chalk each observation on a black board, to be read at once from the ship, in order that the observation may be repeated if any apparent inconsistency presents itself.

Before this process is complete, the Standard Compass should be carried on shore, in order to be compared with the compass used there, by means of the bearing of some distant object, and the difference, if any, is to be recorded; and in all cases, when compasses are compared, the caps, pivots, &c., should be first carefully examined. The shore compass gives correct magnetic bearings.

The **difference** between the **correct magnetic bearing** of the Standard Compass as **observed from the shore,** and the **bearing** of the shore compass as **observed from the ship,** with her head in any particular point, reversed, *i.e.*, with 180° added or subtracted, will show the error on that point which was caused by the ship's iron; in other words, the deviation of the Standard Compass according to the direction in which the ship's head was placed.

282. III.—By Marks on the Dock Wall.—This is a very convenient method where it can be practiced. At Liverpool the correct magnetic bearings of the Vauxhall chimney, from various points of the dock walls, are painted in large figures on the walls, so that the bearing of the same chimney may be observed as the ship swings with the wind and tide; and at the same time that bearing marked on the wall, which is on a line between the Standard Compass and the chimney, is noted.

The **difference** between those bearings is the **deviation** for the point on which the ship's head is at the time.

In a similar manner, at Cronstadt, the correct magnetic bearings of a conspicuous point on a public building are painted on the mole.

283. If, during the operation of swinging, a haze obscures the shore compass, while the sun at the time is shining brightly, a number of points may be secured by time azimuths, which otherwise might be lost. Time-azimuths are also advantageous where the second of the above methods cannot be used for want of an assistant observer for the shore compass; and when the first of the above methods is not available owing to the length of the ship and the scope of the mooring, combined with the most distant objects in sight not being sufficiently far off to render the difference of their bearings insensible as the ship swings round to the tide. In such cases *Godfray's Azimuth Diagram*, as also Azimuth or Sun's True Bearing Tables, computed for intervals of four minutes, by Staff-Commander J. Burdwood, R.N., published by the Admiralty, will be found useful as superseding the calculation for the determination of the True Azimuth.

284. Commander Walker, R.N., has shown* that the deviation may be ascertained with sufficient accuracy by selecting a distant object, as before, "and as the ship swings by wind or tide from one point to another, write down the compass bearings of the distant object opposite the direction of the ship's head. As the ship swings round there will be two nearly opposite points of the compass on which the bearings of the distant object agree, and this should be the correct magnetic bearing of the object." The deviation is then found as in the first method.

285. The Dumb Card.—The difficulty of finding the correct magnetic bearing of the ship's head may be obviated, however, by using the *dumb-card*, *i.e.*, a compass card without the needle, slung in gimbals, with its centre over a fore-and-aft line of the vessel, and as near to its middle as possible. The card is fitted with sight vanes, similar to an azimuth compass. Having obtained the correct magnetic bearing of a distant object, place the card so that it shall point out that direction, and screw the sight vanes to the card, so as to cut the object with the thread. Then, as the ship is swung, the card must still be kept pointing out the correct magnetic bearing of the object by means of the sight vanes, and where the fore-and-aft line meets the edge of the card, must then be the correct magnetic bearing of the ship's head.

286. IV.—By Observations of Amplitudes and Azimuths.—The errors of the compass obtained from observations of celestial objects always contain variation and deviation, and may also be affected by local attraction if the ship be near any disturbing cause. The True Bearing is found by calculation of an Amplitude (pages 198-204) or Azimuth (pages 252-259), and by comparing this with the bearing of the celestial object shown by the compass the correction or error of the compass is found for the direction of the ship's head when the observation was taken. Variation or declination charts give the amount of error due to that cause; and the difference between the variation and the compass error is the deviation. By continuing the process to the eight principal points of the compass a complete table can be found by *Napier's Graphic Method* as explained at pages 365-369.

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* Magnetism of Ships and the Mariner's Compass.

287. To Name the Deviation.—Rule.—*When the reading by the shore compass* (reversed), *or the* correct *magnetic bearing of the distant object, is to the* right *of the reading by the compass on board, the deviation is* easterly; *when to the* left, westerly.

Thus, suppose the *correct* magnetic bearing from the shore compass, with ship's head at N.W., is N. 15° E., and the bearing of shore compass from the ship is S. 11° W.: to find deviation proceed thus:—

Reverse of the bearing by shore compass or correct magnetic bearing	S. 15° W.
Bearing from ship	S. 11 W.
Deviation	4 E.

When the ship's head lies N.N.E., let the binnacle compass bearing of the shore object or compass be N. 19° 30′ E., and the bearing of the binnacle compass from the shore compass be S. 27° 0′ W.: required the *deviation*.

The opposite point to S. 27° 0′ W. is N. 27° 0′ E., which is 7° 30′ to the right of N. 19° 30′ E. Hence the *deviation* is 7° 30′ E.

288. The directions of the ship's head having been taken by the compass in the ship, are therefore affected by the local attraction, and the apparent *compass bearing* of the ship's head differs from the correct magnetic bearing by the amount of the local deviation due to the position of the ship. For instance, when the ship is apparently lying with her head east, it is not the true magnetic east; but supposing the local deviation to be one point easterly, the east point of the compass card will be drawn to E. by S., and the true magnetic direction of the ship's head will be E. by S.

The observations and tabulated results are incomplete until the *correct magnetic* bearing of the ship's head at each observation is found.

289. The following shows the arrangement of tabular forms for finding the deviation by the several processes described.

I. By Bearing of a Distant Object.

Correct magnetic bearing of distant object from ship N. 63° 0′ W., distant 11 miles.

Ship's Head by the Standard Compass.	Bearing of Distant Object by the Standard Compass.	Deviation of Standard Compass.
East	N. 83° 20′ W.	20° 20′ E.
E. by S.	N. 82 15 W.	19 15 E.
E.S.E.	N. 81 5 W.	18 5 E.
S.E. by E.	N. 79 30 W.	16 30 E.
S.E.	N. 77 40 W.	14 40 E.

And similarly at all points of the compass.

II. By Reciprocal Bearings.

Time*.	Ship's Head by the Standard Compass.	SIMULTANEOUS BEARINGS.		Deviation of Standard Compass.
		From Standard Compass on board.	From the Shore Compass.	
$9^h\ 10^m$ A.M.	North	S. 37° 50′ E.	N. 41° 0′ W.	3° 10′ W.
9 14 ,,	N. by E. ..	S. 45 0 E.	N. 42 25 W.	2 35 E.
9 17 ,,	N.N.E.	S. 51 40 E.	N. 43 30 W.	8 10 E.
9 21 ,,	N.E. by N. .	S. 57 20 E.	N. 44 10 W.	13 10 E.
9 26 ,,	N.E.	S. 61 50 E.	N. 45 0 W.	16 50 E.
9 32 ,,	N.E. by E. .	S. 65 30 E.	N. 46 0 W.	19 30 E.
And so on through all the points of the compass.				

290. The seaman must remember that the corrections thus obtained belong to the compass by which the observations are made, and to that compass while it is in its proper place, and that these corrections will furnish no guide whatever to the effects of the iron on a compass placed in any other part of the ship; but if, while swinging, the direction of the ship's head by the other compasses is noted and tabulated, the deviation of all the compasses can be found.

291. It is possible to correct mechanically the compass of an iron vessel in such a manner that the deviations on all courses may be very much reduced or even destroyed altogether.

292. Necessity of Compensation.—The object of applying magnet bars to correct the larger deviations of the compass in iron ships is two-fold: first, the reducing the larger semicircular deviations, which are embarrassing when they exceed a certain amount; and secondly, and more especially, the equalizing of the directive force on different courses. The principles on which their application depends are obvious, for it has been shown that all the polar forces acting in a ship may be represented by an imaginary magnet, and it is therefore certain, from well known laws of magnetic action, that we can neutralise the effect of these disturbing forces by introducing a real magnet whose force has the same magnitude but acts in an opposite direction.

Compensation by magnets does away with one of the errors to which an uncompensated compass is liable. There are changes to which the magnetic condition of an iron ship is subject, but in addition to these sources of error an uncompensated compass changes its deviation with any alteration that occurs in the amount of the earth's horizontal force, and this takes place when the ship changes her station on the earth's surface; for instance, if from sub-permanent magnetism in the Bay of Bengal an uncompensated compass had a deviation of ten degrees, in the Gulf of St. Lawrence it would have a deviation of thirty degrees.

If the deviations are large in amount embarrassments are produced, since the angular movement in azimuth of the ship's head is not represented by a similar apparent angular movement. For example, a compass placed above the aft side of the round-house on board of vessel with the ship's head N. 1° W., correct magnetic, the ship's head appeared by compass to be N.W. by W., but when her head was swung four degrees to the left, viz., to N. 5° W., correct magnetic, her compass would move round ten points, full twenty-eight times as much as the real change of the position of the ship's head. This of itself is embarrassing to the seaman; in the same ship, with her head in opposite azimuths to the above, the earth's directive force is reduced nearly one-half by the antagonism of the ship's force. This gives sluggishness to the compass, and increases the effect of friction, and other disturbing causes.* The neutralization of the ship's polar force, *i.e.*, the reduction of the semicircular deviation by the introduction of an opposing magnet, necessarily allows the earth's directive force to act equally on the ship's compass needle in all azimuths.

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* The time—as taken by compared watches—may be omitted if the shore observations can be clearly made out by being chalked on a black board.

The necessity for compensation by bar magnets is greater now than formerly, since the greater introduction of iron beams, decks, transverse bulkheads, &c., has conduced to the great decrease of directive force of the compass needle in all parts of the ship.

The average force is thus commonly reduced one-fourth from its value on shore, or to three-fourths of its proper value; and the force, where the ship's head is in the direction near to that of her head while building, is in many cases, reduced to about one-third of that average, or to one-fourth of its proper value, and in some cases is even reversed. These facts not only show the necessity of compensation by magnets, but also the necessity of employing the most perfect compasses in the modern types of iron ships.

293. A compass compensated by iron chain, or cast iron correctors, is less affected by the heeling of the ship than the same compass would be if uncompensated, and, consequently, is less disturbed by the rolling of the ship. The last-named advantage is greatly increased when the compass is compensated for the effects of heeling by a vertical magnet.

294. The theory of magnetism being understood, the compensation becomes a simple matter. We have two descriptions of deviation to compensate, the polar and quadrantal. The former, as has been seen, is the result both of the sub-permanent magnetism of the ship and the inductive magnetism of vertical iron. While the ship is in the same magnetic latitude the deviation arising from both these may be compensated by steel magnets, but the quadrantal deviation can only be compensated by soft or cast iron, because permanent magnets produce contrary deviations with the ship's head in opposite directions, but quadrantal deviation is of the same name at opposite points.

Neglecting for the present the vertical component, the action of the ship on the needle may be represented by that of a large magnet N S, Fig. 87, or still further resolved into the action of two magnets S′ N′ and S″ N″, at right-angles to each other, one longitudinal in the midship line, the other transversal to the ship, or athwartship. When the ship's head is placed North or South the transversal force alone disturbs the compass, and the quadrantal disturbance vanishes, and the transversal magnetic part can be corrected by an opposite transversal magnet, N_3 S_3, broadside-on to the compass, whose distance is determined without any calculation, simply by trying its effect at different distances till the needle points correctly, *i.e.*, N. when S″ N″ is corrected.

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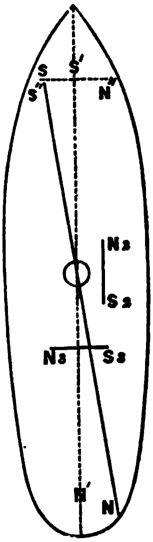
* It is well to remember that the loss of directive force in the uncorrected compasses of iron ships occurs on those courses which are on and near to the direction of the ship's head in building; in other words, the magnetic force of the ship is then in direct antagonism to the earth's directive force.

Fig. 87.



Then, in like manner, if the ship's head is placed East or West, the longitudinal magnetism only disturbs the compass, as the quadrantal deviation vanishes there, and it is to be corrected by a longitudinal magnet, N_2 S_2, broadside-on to the compass tentatively applied, when the needle will point N. when N″ S″ is corrected.

If the magnetic axis of the vessel coincides with its midship line, no athwartship magnet N_3 S_3 will be required, and it is evident also that if the direction of N S is known, only one magnet N_4 S_4, *parallel to it,* need be used, but as in practical work this is rarely known, the two magnets are used.

The effect of permanent or sub-permanent magnetism are now entirely corrected. In order to correct for the inductive effect which produces quadrantal deviation, the ship's head must be placed in azimuth 45° (nearly), *i.e.*, N.E., S.E., N.W., or S.W.; there will be no difficulty in ascertaining whether the quadrantal disturbance is such as corresponds to the effect of iron in the direction of the ship's head, and, if so, it must be corrected by trial till the correction is complete.*

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* This method of correction by permanent magnets is known as AIRY's method, it having been proposed by the Astronomer Royal of England.

295. Compensation of Semicircular Deviation.—To distinguish quadrantal deviation from polar deviation is easily accomplished, but to distinguish that part of polar magnetism arising from induction in vertical iron from that which is produced by sub-permanent magnetism is a more difficult task. Yet, with regard to vessels making voyages to the southern hemisphere, this is of the highest importance. For ships that cross the equator, and in which the steering compasses are placed very near to the rudder head and the vertical iron in the stern of the ship, movable magnets may be used in order to counteract the inductive magnetism of those vertical masses on change of magnetic latitude; but it has been proposed to neutralise the injurious effect of this arrangement by fixing in the ship a vertical bar of iron in front of the compass, at such a distance that the inductive changes which occur in it shall, as nearly as possible, balance the changes in the vertical masses abaft the compass. This compensating bar, which may vary from two to three inches in diameter, it is proposed should reach from the keel to about the height of the compass. In a modified degree this arrangement, as originally proposed by Mr. Rundell, Secretary to the Liverpool Compass Committee, was carried out in a few ships at Liverpool under his superintendance, and found beneficial. It is an arrangement requiring much skill to carry out successfully.

The order of proceedure for compensation is as follows:—If you cannot trust your eye, draw two chalk-lines—one fore-and-aft and the other athwartship—crossing each other under the centre of the compass. Then to compensate the part of the sub-permanent magnetism, resolved to either of the ship's sides represented by + C (*i.e.*, if the deviation is Easterly with the ship's head North, or Westerly with the ship's head South) or by — C (*i.e.*, if the deviation is Westerly with the ship's head North, or Easterly with the ship's head South), it will be necessary to bring the ship's head *correct* magnetic North or South, and place the *compensating* bar magnet *athwartship* either before or abaft the compass at right-angles to the fore-and-aft midship line and parallel to the ship's deck, with the middle of the magnet's length in the vertical plane passing longitudinally through the centre of the compass card. The N. marked end (*red* pole) of the magnet being directed to that side of the ship towards which the N. end (*red* pole) of the compass appears to be drawn. Thus, if the N. marked end (*red* pole) of the needle be drawn to starboard, causing a + C, this must be compensated by placing the N. end (*red* pole) of the bar magnet directed to the starboard side of the ship; but if by the ship's attraction the *red* end of the needle be drawn to *port*, causing a — C, then the *red* pole of the magnet must be directed to port. The distance of the magnet is to be determined by trial, beginning by placing the magnet at a distance from the compass and gradually approaching it until the compass shows correct magnetic North or South. If C be large, two magnets, one before and one abaft the compass, may be necessary.

Thus, Fig. 88 shows a ship built head East (giving co-efficient + C) her head being brought to *correct* magnetic North; the North or *red* end of the compass needle being drawn to the starboard side. This is compensated by a 'thwartship magnet-bar with the North or *red* pole of it directed to star-

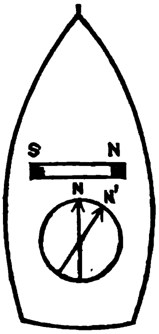

Fig. 88, + C.

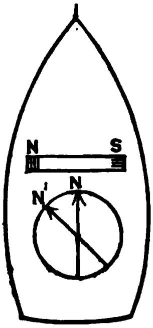

Fig. 89, — C.

board, and thus repels the North end of the compass needle to its normal *correct* magnetic direction.

Fig. 89 represents a ship which was built head West (giving co-efficient — C) with her head swung *correct* magnetic North, and consequently the N. or *red* end of the needle is attracted to the port side, which attraction is compensated by placing a 'thwartship magnet with the N. or *red* end directed to port, thus repelling the N. end of the compass needle to its normal *correct* magnetic direction.

To compensate for the attraction towards either the ship's bow or stern, represented by the co-efficient + B (*i.e.*, when the deviation is Easterly with ship's head East, or Westerly with ship's head West) or by the co-efficient — B (*i.e.*, when the deviation is Westerly with the ship's head East, or Easterly with ship's head West). With the ship's head East or West *correct magnetic* place a magnet on the deck in a fore-and-aft direction, with its centre on the athwartship line (either to port or starboard of the compass), the N. marked (or *red*) end of the magnet bar being directed to that part of the ship towards which the north end of the compass needle appears to be drawn. Thus, if the N. (or *red*) end of the needle be drawn towards the bow causing a + B, the N. (or *red*) end of the magnet bar must be directed forward to neutralise this effect; but if the N. (or *red*) pole of the needle is attracted towards the stern, causing — B, the *red* end of the magnet must be placed aft. The magnet must be moved to or from the intersection of the lines till the needle points correctly. If the ship was built with her head nearly North or South two magnets may be required. These may either be placed one on each side of the compass or both on the same side, as may be most convenient.

If the ship's head be now placed on the two opposite cardinal points, it may be found that a small deviation still exists, in which case the magnets may be again slightly moved on their respective lines to reduce this residual error within the smallest limits.

Fig. 90 shows a ship, built head South (producing co-efficient + B), with her head swung to East (*correct* magnetic), and, consequently, the N. or *red* end of the needle is attracted towards the bow, which is compensated by a

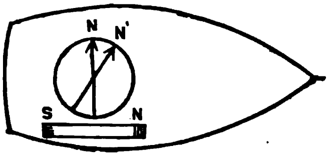

Fig. 90, + B.

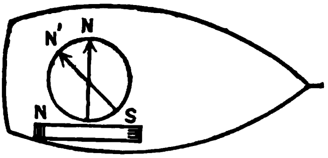

Fig. 91, — B.

fore-and-aft magnet, the N. or *red* pole of which is directed to the bow, and thus repels the N. or *red* end of the compass needle to its normal *correct* magnetic direction.

Fig. 91 represents a ship which was built head North (giving co-efficient — B) brought with her head *correct* magnetic East, and hence the N. end of the needle is attracted towards the stern, which is compensated by a fore-and-aft magnet, the N. or *red* pole of which lies aft and thus repels the N. or *red* end of the compass needle to its normal correct magnetic direction.

In making this correction it is advisable to leave about 1½° of the semicircular deviation uncorrected at the North and South points, and about ½° at the East and West points; the deviation so left to be westerly if the ship has been swung from left to right, East if swung from right to left. This small correction arises from the noticeable fact that when an iron ship is swung to the left a temporary + A and + E are introduced, and when to the right a temporary — A and — E. These it is, of course, best to leave uncompensated.*

We are indebted to M. Gaussin, of l'Ecole du Génie Maritime, for this fact, which has been verified by the discussion of numerous deviation tables of H.M. ships. It doubtless arises from the slowness of soft iron in receiving and parting with its full charge of induced magnetism.

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* But these co-efficients A and E, observed while swinging a ship are most frequently only transient from the fact that induced magnetism is not instantly parted with. For example, while a ship's head is West the athwartship iron acquires a certain amount of red polarity on the starboard side which does not produce any deviation while her head remains West, because it acts on the needle in the same line as the earth's horizontal force. But when the ship's head is swung to the North, although the greater part of this transient magnetism has ceased to exist, the starboard ends of the athwartship iron still retains a small portion of red polarity, and the port ends blue; and being then at right-angles to the earth's line of force, repel the red or North pole of the needle, producing westerly deviation. Also, the fore-and-aft iron while the ship's head is either North or South acquires a transient magnetism that it does not immediately part with, but this does not produce so great an amount of deviation as the athwartship iron, because the poles of the fore and aft iron are further from the needle. In this case the ship is supposed to be swung from West to North—that is, with the sun; in which case A and E would be minus, producing westerly deviation on the North and South quadrants, and easterly on the other two; but if the ship were swung in the contrary direction—that is, against the sun; both A and E would be plus.

If the co-efficient A should be large—that is, more than two degrees—the compass card should be examined so as to guard against the apparent existence of A, since this co-efficient may be simulated by the compass needle not having its red and blue poles coinciding with the North and South points of the compass card. This may be done very conveniently by bringing the blue pole of a thin magnet outside the bowl of the compass to where the North point of the card is directed, keeping the blue edge of the magnet vertical. Then, if this magnet does not agree with the North point of the card of the compass, there will be a co-efficient A on account of the needle of the compass not being correctly attached to the compass card.

296. Compensation of Quadrantal Deviation.—*After* the semicircular deviation has been corrected by magnets the compensation of the quadrantal deviation remains to be made. This is effected by a mass of soft iron placed on the same level as the compass needle, so as to cause opposite effects to those of the ship.* The ship's head should be swung to one of the quadrantal points, N.E., S.E., S.W., or N.W. *correct magnetic.* Sir George B. Airy recommends boxes filled with iron chain, attached one on each side of the binnacle to be used. The small quadrantal values of 2° to 3° are commonly corrected in this way, but for larger deviations soft cast iron cylinders with hemispherical ends, as recommended by the Liverpool Compass Committee, have been successfully employed. The best corrector for this purpose, however, is a couple of hollow cast iron globes or shells, the introduction of which is due to Prof. Sir William Thompson. The error to be corrected is generally of the form + D, the quadrantal deviation of almost every ship being *Easterly* in the N.E. and S.W. quadrants and *Westerly* in the N.W. and S.E. quadrants; hence these correctors should be placed athwartships, on the same horizontal plane, and at equal distances, on the starboard and port sides of the compass; the distance should be determined by trial, moving them to or from the compass till the needle points correctly, but not nearer than 1½ times the length of the needle from the centre of the card. If chain boxes are employed this compensation should be effected by putting more or less chain into the box. In the very unusual event of D being negative, *i.e.*, when the deviation is *Westerly* on the N.E. and S.W. points or *Easterly* on S.E. and N.W., and large, the correctors or chain boxes should be placed on the fore-and-aft ends of the binnacle.

These correctors are too frequently absent, and it should be remembered that they very essentially improve the action of the compass, not only diminishing the deviation, but increasing the directive force.†

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* They effect their pupose by becoming magnetised by induction. For example, with ship's head N.E. the *port* ends have *red* magnetism, and in this position compensate *easterly* deviation; but on turning the ship round to N.W. their *starboard* ends acquire *red* magnetism, and in this new position compensate *westerly* deviation.

Quadrantal correctors produce their greatest effect on N.E., S.E., S.W., and N.W., being zero at North, South, East, and West. When the ship's head is North and South, correct magnetic, the poles of cast iron cylinders being at right-angles to the line of force are powerless to affect the compass; and when the ship's head is East or West, correct magnetic, though the cylinders are then magnetic they cannot affect the compass as their poles are parallel to the needle. In the case of cast iron globes the magnetic poles are parallel to the needle on all four of the last named points, but the effect is the same as with the cylinders.

Although the quadrantal deviation is rarely large in amount like the semicircular, it is for many reasons very important that it should be corrected. Not the least is the fact that for the same amount of maximum error the quadrantal changes twice as rapidly as does the semicircular error; and, therefore, a quadrantal error of 10° is much more embarrassing than a semicircular one of the same amount. The true significance of this will be evident, when it is considered that a quadrantal error of 10° implies a rapid change in the deviation of a compass, amounting to as much as half a point with so small a change as a point and a half in the ship's course from one side to the other of any of the four cardinal courses. The difficulty of steering by such a compass will be evident.

† Masses of iron of a spherical or cylindrical shape, placed near the level of the compass in a fore-and-aft line, are beneficial in increasing the directive force, but prejudicial in increasing the quadrantal deviation; if placed on the port or starboard side they are doubly beneficial, as they both increase the directive force and diminish the deviation. Iron masts which may be compared to a vertical cylinder of infinite length, do not increase the directive force, but increase the quadrantal deviation, and are so far slightly prejudicial. It is here understood that the compass is not placed near the heel or head of the masts, which parts are, of course, powerful poles.

This soft iron thus applied corrects D. E, which is due to soft iron unsymmetrically distributed, may be corrected by moving the soft iron either backwards or forwards, but it is usually very small and may be neglected. The magnets used for compensating should be of good steel, made very hard and well magnetised some time (some months if possible) before being used, so as to acquire a permanent condition of magnetism. They may be from fourteen inches to two feet in length, and about ½ in. by 1½ in. cross section.

297. When, however, this part of the deviation is large, and a compass with a single needle is employed, neither chain-boxes nor correctors will give a satisfactory compensation. There arises what has been called an octantal deviation, caused by chain boxes or correctors being further distant from the poles of the needle when on two point courses than when on either of the six point courses. On this account the use of long needles is adverse to good compensation. This octantal deviation is, however, much reduced by using double-needle cards, in which the ends of the parallel needles are 60° apart. Objections have, however, been made to the use of correctors; one being the inconvenient position in which they are required to be placed exposing the compass to accidental injury, and another the difficulty of procuring correctors free from permanent magnetism. To obviate these difficulties it has been proposed that two compasses should be placed in the same transverse line, and so near as to produce in each other a *negative* quadrantal deviation sufficient to correct the *positive* quadrantal deviation which each would otherwise have. There is, however, among other objections to this mode of compensation, one which seems conclusive. Uncompensated quadrantal deviation undergoes no change when the ship alters her magnetic latitude; but a compass compensated in this manner in one latitude would be correct in such places only where the horizontal magnetic force was the same, and would necessarily require repeated adjustments. For these reasons the plan was rejected by the late Astronomer Royal, Sir G. B. Airy.

298. It frequently happens that one correction will interfere with one already made, and it is therefore necessary to repeat the adjustments with the head in different positions, so as to eliminate the errors, or if any obstinately remain, they must be noted to make a deviation table, for the corrections are rarely so perfect as to dispense with one.

Fig. 92.

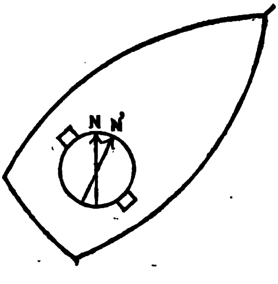

Fig. 92 also illustrates the position of the soft iron correctors on the starboard and port sides of the compass in order to compensate a *positive* quadrantal deviation, the ship having been swung to the quadrantal point N.E.

The foregoing figures show the position of the bar magnets when used to correct the deviation of ships built with their head in the direction of one or other of the cardinal points; but since it is only occasionally that a magnet placed athwartship or fore-and-aft is sufficient for the compensation, as the majority of ship's are built on one or other of the other intercardinal points, and thus a magnet in each of the two positions referred to will most probably be required. Therefore, besides the arrangement of magnets in Figs. 88, 89, 90, 91, there are others, viz., for different combinations of B and C, and Fig. 93 may be taken as representing a vessel after being adjusted lying head East, but having been built head N.E., and, hence, with a — B and + C, and requiring an arrangement of magnets as in annexed figure.

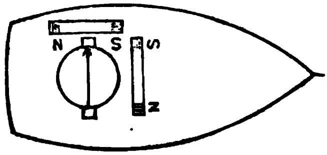

Fig. 93. — B and + C.

Fig. 93 also shows the position of the correctors on the port and starboard sides of the compass for a *positive* quadrantal deviation.

299. Correction of the Heeling Error.—This is effected by having a square groove cut in the pillar which supports the compass and inserting a magnet in a vertical position immediately below the centre of the card when the ship is exactly upright. The compass having been compensated when upright, as described in Arts. 295, 296, when practicable the ship should be heeled to starboard 10°, with her head in the direction which was north by compass when she was upright. If the needle be drawn to the west, which will be indicated by the ship's head appearing east of north by compass, the magnet should be placed in the groove with that pole which repels the N. (*red*) of the needle uppermost, and must be slid along the groove and clamped sufficiently near the needle until the ship's head appears north by compass. But in the exceptional cases in which the N. (*red*) end of the needle is drawn to leeward, which with a starboard heel before the magnet was in place would make the ship's head appear west of north, the pole that attracts the N. (*red*) end of the compass should be uppermost. In other words, if, as is generally the case, the heeling error is to windward the N. or *red* end of the magnet must be uppermost, but if to leeward the S. or *blue* end uppermost.*

It sometimes occurs that the compass is more affected by heeling to starboard than to port, and at other times the reverse; therefore the ship should now be heeled to port, and if the ship's head still appear North by compass the compensation is perfect; but if not, one-half must be allowed for heeling in each direction; for example in the case of the Standard Compass of an iron vessel the vertical magnet was so placed as to cause no change of deviation when she was heeling to starboard, but when heeled 10° to port, with her head North by compass, she was found to be over compensated 3°, which was indicated by the needle being drawn 3° to the lower side of the ship, the ship's head being N. 3° E. by compass. This error being divided between the starboard and port heel, and the vertical magnet lowered until the ship's head bore N. 1° 30′ E., the compass having a change of deviation amounting to 1° 30′ W., either by heeling 10° starboard or 10° port.*

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* In the Royal Navy the general practice is to employ a cylindrical magnet, about seven inches long and three-fourths of an inch thick, which is inserted in the supporting pillar of the Standard Compass, a cylindrical hole being accurately bored for the purpose, but allowing a free movement for the magnet up and down.

It must, however, be remembered that the correction for the heeling error is only, in general, exact for one latitude—the magnetic latitude where it was made—and must be tested on any considerable change of latitude by observing the effect of the heeling of the ship on a N. or S. course, or by observing the vertical force, *i.e.*, determining it. The sub-permanent magnetism below the compass produces the same result in all latitudes. That part which depends on permanent vertical force varies inversely as the earth's horizontal force, and, therefore, will diminish as we approach the equator and increase again as we pass it, whilst that part which depends on the induction of the vertical force in soft iron varies as the tangent of the dip, and, therefore, becomes zero and changes its sign as we pass the equator; unless, therefore, we know the proportion of the vertical force which arises from permanent magnetism to that which arises from induction in soft iron we cannot predict with much confidence the change which will take place in the heeling error, and, hence, the desirability of determining independently the heeling error with the ship's head N. and S. whenever an opportunity offers on any distant voyage. After crossing the magnetic equator it may, in some cases, be desirable to remove the vertical magnet, and, in high south latitudes, to place it in a reversed position, especially if there be much oscillation of the compass in bad weather.†

300. The late Astronomer Royal, Sir G. B. Airy, has recommended that an arrangement should be made to enable masters of iron ships to correct any changes in the deviation by bringing the compensating magnets nearer to, or removing them further from, the compass, as the case may require. The correct magnetic bearing of a visible point being known, or the magnetic bearing of a celestial object being computed beforehand for a time azimuth, place the ship, by means of a dumb card,[*] with her head correct magnetic N. or S., and move the athwartship magnets till the compass points correctly, or with the same deviation as in port.

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* The distance at which the vertical magnet ought to be placed below the compass may be accurately ascertained by either of two methods which are given in the *Admiralty Manual*, pages 145-146; but we may approximately correct the heeling error of the Standard Compass of an ordinary iron ship, having its quadrantal deviation *uncorrected*, by moving the vertical magnet until nine vibrations of the vertical dipping needle on board occupy the time of ten vibrations on shore.

Or, if the quadrantal deviation has been corrected, then by moving the vertical magnet till 39 vibrations of the dipping needle on board occupy the time of 40 on shore.—*Admiralty Manual*, page 147.

† The heeling error not only causes deviation, but also unsteadiness, and in some cases when a ship has rolled with her head North or South by compass, the card has spun, and this has rendered it impossible to keep the ship on any required point. It is not, however, always found that compasses having the largest heeling error are most productive of this inconvenience. This unsteadiness depends on two conditions: first, the amount of the change of the deviation arising from any number of degrees of heeling; and, second, the existence, or non-existence, of isochronism between any number of the periods of the vibrations of the card and any number of the ship's rolling. Taking this latter condition into consideration, when inconvenience has been experienced arising from the unsteadiness of the compass, the card has been changed, since either a more sluggish or more active needle could be more or less in unison with the ship's roll. With a compensated card, while the ship remains in the same latitude, if we choose a card which is steady when the ship rolls with her head North or South, it will, also, be steady when her head is in any other direction. Still cases have occurred in which a compass that is steady in one latitude has vibrated, and even spun, when, by changing the ship's place, the earth's horizontal force has changed. To obviate this difficulty, washers, made to rest on the card with the cap passing through the middle, have been employed with advantage.

Then, similarly, place ship's head correct magnetic E. or W., and move the fore-and-aft magnets until the compass indicates E. or W. correctly, or the remaining deviation is restored. In adjusting the *athwartship magnets* care must be taken that the *ship is upright*. By this means the same table of remaining deviations may be used throughout the voyage, whilst the ship is upright; whereas, had the magnets been so placed as to give no deviation on either of the two cardinal points on which observations had been made, the seaman would be left in doubt as to the amount of deviation when the ship's head was on any other point. For the above purpose an azimuth compass may be used instead of a dumb card, by stopping the card with the cardinal point, at which the ship's head has to be brought, at the lubber line.

After all the compensations have been accurately performed, there will still remain small residual errors, for these the ship must be swung and a table of deviations made for use.

NAPIER'S DIAGRAM.

301. It is often of the utmost importance in various branches of physical science to represent tables of *related numbers* by means of curve lines, or other figures that show *to the eye* the nature of the relations or laws expressed, or rather concealed, within the mass of figures constituting the tables. Not only does such a mode of representation at once manifest these laws—almost rendering them palpable—but it further points out in what cases natural laws are not represented, and therefore what the cases are that require a greater amount of observation. These modes of representation are commonly known as *Graphic Methods.*

Various "graphic methods" of delineating the deviation have been devised;[†] but the method introduced here is due to J. R. NAPIER, Esq., F.R.S., and is one peculiarly adapted for this purpose, as it is equally applicable whether the points on which the observations have been made are or aré not precisely equidistant. It requires no calculation, and only a moderate degree of neat-handedness.

The method consists of two parts, the diagram and the curve. The diagram is the same for all vessels.

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[*] Or BAIN and AINSLEY's Course Corrector may be used for this purpose.

[†] Graphic Methods for correcting the ship's course for the Deviation of the Compass have also been designed by Rear Admiral RYDER, Mr. ARCHIBALD SMITH, F.R.S., and Mr. W. W. RUNDELL. Admiral RYDER's which is an extension of NAPIER's diagram, is published by the Admiralty. Mr. SMITH's, known as the straight line method, is published by the Board of Trade, and also furnished to H.M. ships for fleet tactics, for which it is well adapted. Mr. RUNDELL's is known as the circular method. They are all useful in practice.

302. Construction of the Diagram.—In this method the diagram consists of a central or vertical line of convenient length—say 18 inches—which may be considered as representing the margin of the compass card cut at the north point, and straightened and extended in the following way:—

N E S W N

This line, which may be taken to represent no deviation, is divided into 32 equal parts, representing the 32 points of the compass, commencing at the top with North, and ranging in the order of N. by E., N.N.E., &c., and ending with North at the bottom. The central line is then intersected at each of the 32 points by two straight lines, one a *plain* line and the other a *dotted* line. The plain and dotted lines make an angle of 60° with the central line and with each other, and with the parts of the central line intersected form a set of equilateral triangles, and so converting the diagram into a simple addition and subtraction table. On the right side of the central line the *dotted* lines incline *downwards*, and the *plain* lines *upwards*. The reverse is the case on the left. In other words the central line is intersected at the angle of 60° by dotted lines drawn upwards from right to left, and at the same angle downward from right to left by plain lines. The central line is further divided into 360 equal parts, representing degrees, and these divisions are numbered from 0° at the top to 360° at the bottom. They are also numbered, according to the usual mode of dividing the compass card, from 0° at North and South, up to 90° at East and West. This division of the central line into degrees serves also as a scale by which the deviations are laid off.

It is very important to remember that the plain lines always represent Magnetic Courses, and the dotted lines Compass Courses.

303. Requisite Observations to be made.—The least number of observed deviations available for obtaining a complete curve are the deviations on 4 points distributed equally, or nearly so, round the compass; but, if possible, the deviations should be observed on 8 or more points. If the observations are observed on 4 points only, these should be at or near N.E., S.E., S.W., and N.W., and from these it is possible to form a fairly approximate curve. The points next in importance are North, East, South, and West. If the deviations have been observed at or near the eight principal points, a curve can be drawn which will give the deviation on every point of the compass within very small limits of error.*

304. Cases may also occur in which by the ship swinging round at her anchors in a tide-way or to the wind, or by the aid of a steam-tug, the deviation may be observed on various directions of the ship's head, not being necessarily exact points of the compass; or, similarly, whilst under steam or sail at sea, a number of azimuths of the sun may be observed, and hence the deviation obtained.

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* The examiation of a collection of curves made from actual observations, as in the report of the Liverpool Compass Committee, &c., will show that there is so much regularity that these interpolated deviations may generally be relied upon, although certain cases, such as the U.S.S. *Roanoke* (Report of Nautical Academy of Sciences, 1863), the irregularities are considerable.

In these cases the Graphic Method here described furnishes a ready and effectual mode of obtaining a result on which the errors of individual observations are as far as possible compensated and any egregious errors eliminated.

305. Construction of the Curve of Deviations.—Easterly deviations are laid down to the **right** of the central line, **westerly deviations** to the **left.***

The amount of the deviation is taken from the scale of degrees on the central line; then, if the deviation has been determined with the ship's head on an exact compass point, lay off the amount of the deviation on the *dotted*† line which passes through that point; but if not observed on the exact point, then on a line parallel to the dotted line, the compass course or direction of the ship's head being still taken from the central line, and mark the point so determined with a cross, or dot encircled in ink. Perform the same operation for each observed deviation. Then with a pencil and a light hand draw a flowing curve, passing as nearly as possible through all the crosses, or dots encircled; and when satisfied that the curve is good, draw it in ink. This is the curve of deviations.

If any of the pencil marks be out of the fair curve, it may be assumed that an error has been made in the observation for that point.

NOTE.—When the curve alters its form considerably near the North point as in several CURVES, EXAMPLES FOR PRACTICE, it will be advisable to bring the North points of the diagram together in the form of a drum and then draw the curve.

The process will be best understood by explaining the projection corresponding to the observations as given in the following table:—

Ship's Head by Standard Compass.	Deviation.	Ship's Head by Standard Compass.	Deviation.
North	6° 30′ W.	South	5° 30′ E.
N.E.	13 0 W.	S.W.	28 35 E.
East	22 15 W.	West	19 15 E.
S.E.	23 30 W.	N.W.	3 0 E.

Deviation Curve C in Diagram.

1. The first compass course on which an observation has been made is North, and the observed deviation is 6° 30′ W. With a pair of dividers take from the central line a distance equal to deviation 6½°, and from North on the central line lay off the deviation on the dotted line which passes through that point towards the left—the deviation being W.; at the extremity of the distance make a dot or cross.

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* In Rear Admiral RYDER's plan, the central line is the diagonal of a square and the other lines make angles of 45° with it, and at right-angles to each other and to the sides of the square, which sides are divided into 360°; the top and bottom representing correct magnetic courses, the sides compass courses. By this method the correct magnetic course corresponding to a given compass course, or the compass course corresponding to a given correct magnetic course, is found as by a table of double entry. The two methods, it will be seen, are the same in principle. Mr. NAPIER's will perhaps be found more convenient in construction by the expert; Admiral RYDER's more simple in use by the inexpert.

† If the table of deviations are given for the correct magnetic courses and not the compass courses or direction of the ship's head, the same process is gone through, except that the deviations are in that case laid off on the plain lines. It is, however, now generally understood that this procedure is contrary to practice and may lead to error.

2. The second compass course on which an observation has been made is N.E., and the observed deviation is 13° 0′ W. With dividers take from the central line a distance equal to deviation 13°, and from N.E. on the central line lay it off on the dotted line—to the left—deviation being W.: and the point so determined mark with a cross or dot.

3. The third compass course on which an observation has been made is East, and the observed deviation is 22° 15′ W. Take from central line 22¼°, and from E. on central line and on the dotted line passing through it, lay off the observed deviation to the left—deviation being W.; and mark the point so determined with a dot or cross.

4. Compass course S.E., observed deviation 23° 30′ W. Take from the central line a distance equal to deviation 23½°, and from S.E. on the central line lay off on the dotted line passing through the same point the amount of deviation—to the left—the deviation being W.; make a dot.

5. Compass course South, deviation 5° 30′ E. Measure on the central line a distance equal to deviation 5½° and having found compass course South on the central line, lay off the amount of deviation on the dotted line which passes through it towards the right—deviation being E.; and make a dot or cross.

6. Compass course S.W., deviation 28° 35′ E. From the central line take a distance equal to observed deviation 28½°, and having found S.W. on the central line, lay off on the dotted line passing through that point the amount of deviation to the right—deviation being E.; make a dot or cross.

7. Compass course West, observed deviation 19° 15′ E. Measure on the central line a distance equal to deviation 19¼°, and from West lay off on the dotted line passing through that course the amount of deviation towards the right—deviation E.; and make a dot or cross.

8. Compass course N.W., deviation 3° 0′ E. Take from central line a distance equal to 3°, and lay off on the dotted line passing through N.W. the amount of deviation (3°) towards the right—deviation E.; and make a dot.

9. Then, with a pencil and a light hand, draw a flowing curve, passing as nearly as possible through all the crosses or dots, and if satisfied with the curve in pencil, draw it in ink.

Note.—The learner should take a pair of dividers and go through the above process on the diagrams here given (see Plate I). He should then take the blank diagram (see Plate II), and make the curve on it.

Ex. 2. Construct a curve of deviations, using for the purpose the following observations:— (See Deviation Curve A in Diagram).

Ship's Head by Standard Compass.	Deviation.	Ship's Head by Standard Compass.	Deviation.
North	1° 15′ W.	South	1° 50′ E.
N.E.	22 30 E.	S.W.	15 0 W.
East	26 50 E.	West	26 0 W.
S.E.	17 0 E.	N.W.	27 0 W.

The following describes the process of construction:—

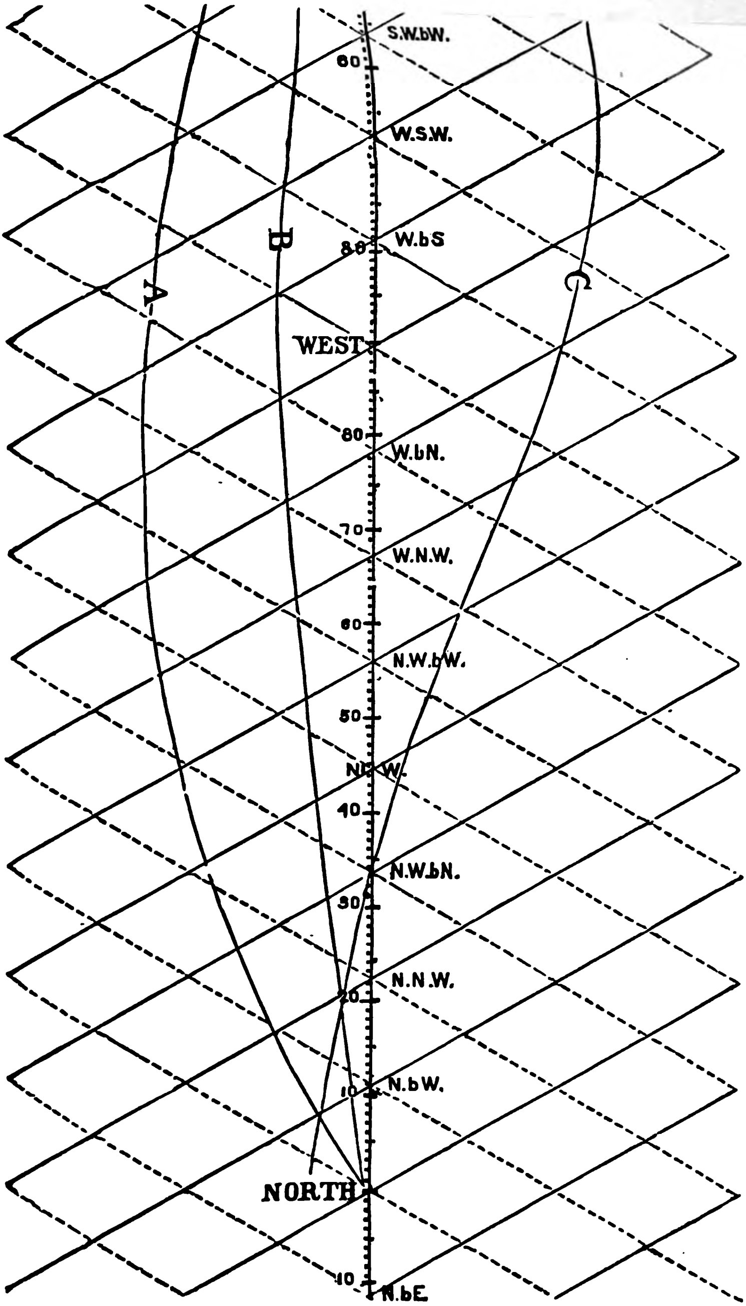
1. With a pair of dividers take from the central line a distance equal to deviation 1° 15′, or 1¼°, and from North on the central line, lay the distance off on the dotted line passing through that point and towards the left—being W.; at the extremity of the distance make a dot or cross.

2. Take from the central line a distance equal to 22½° (22° 30′), and lay it off on the dotted line, from N.E. towards the right—being E.; make a dot or cross.

NAPIER'S DIAGRAM,

Showing Curve of Deviation.

Ship____



3. Take from the central line a distance equal to 26¾° (26° 50′), and lay it off on the dotted line, from East towards the right—being E.; make a dot or cross.

4. Take from the central line a distance equal to 17° (17° 0′), and lay it off on the dotted line, from S.E. towards the right—being E.; make a dot or cross.

5. From the central line take a distance equal to 1¾° (1° 50′), and lay it off on the dotted line, from South towards the right—the deviation being E.; make a dot or cross.

6. From the central line take a distance equal to 15°, and lay it off on the dotted line, from S.W. towards the left—the deviation being W.; make a dot.

7. From the central line take a distance equal to 26°, and lay it off on the dotted line, from N.W. towards the left—deviation being W.; make a dot.

8. From the central line take a distance equal to 27°, and lay it off on the dotted line, from W. towards the left—deviation being W.; make a dot.

9. Repeat the admeasurement first made, from North, at the lower end of the central line.

10. Then, with a pencil and a light hand, draw a flowing curve, passing as nearly as possible through all the dots or crosses; when satisfied that the curve is good, draw it in ink. This is the curve of deviation.

Ex. 3. Construct a curve of deviations, using for the purpose the following observations:— (See Deviation Curve B in Diagram.)

Ship's Head by Standard Compass.	Deviation.	Ship's Head by Standard Compass.	Deviation.
North	0° 22′ W.	South	0° 16′ W.
N.E.	7 14 E.	S.W.	6 16 W.
East	10 44 E.	West	11 50 W.
S.E.	6 18 E.	N.W.	7 52 W.

Selecting those dotted lines which pass through the points representing the different directions of the ship's head, the deviations are laid off: thus, at North, we mark off 0⅓° (0° 22′) to the left on the dotted line passing through North—because deviation is West; at N.E., we take 7¼° from the central line, and lay it off to the *right* (deviation being E.) on the dotted line passing through N.E.; at East, 10¾° is taken from the central line and laid off to the right on the dotted line passing through East; and so with the others, being careful to remember that the known deviations must be laid down on the *dotted* lines, *easterly* to the *right* and *westerly* to the *left* of the central line. The curve is then drawn neatly through all the points so laid down.

306. How the Curve is used.—The curve of deviations having been completed, the diagram affords a ready and convenient method of applying the deviation to the ship's course. This correction may be required as follows:—1st, from the **compass course** which has been steered, it may be required to find the **correct magnetic course** to be laid down on the chart; 2nd, from the **correct magnetic course given** by the chart, it may be required to find the **compass course** on which the ship's head ought to be kept; 3rd, if one or more bearings of the land are taken, to **correct these bearings** by the amount of the **deviation** *due to the direction of the ship's head at the time.* The corrections are given by the following rules:—

307. To find the **Deviation** on any **Compass Course.**

RULE XC.

On the central *line find the given* course; *then, with a pair of dividers, measure the* distance *from that* point *to where the curve cuts the* dotted *line passing through the course; but if* no dotted line *proceeds from the course, then measure from the course on the central line to the curve in a* direction exactly parallel *to the nearest* dotted lines: *that distance measured on any part of the central line will give the deviation in degrees.*

EXAMPLES.

Ex. 1. What is the deviation on Compass Course N.E. by N. (*a*) for the deviation curve B; (*b*) using the deviation curve A?

(*a*) Having found the given course on the central line, with a pair of dividers measure the distance from N.E. by N. to where the curve cuts the dotted line proceeding from that point; this distance taken to the central line gives 6° E.

(*b*) Measuring with a pair of dividers the distance from N.E. by N. to where the curve cuts the dotted line proceeding from that point, the deviation measured on the central line is found to be 19° E.

Ex. 2. Required deviation in compass course W.S.W., using deviation A.

Find W.S.W. on the central line, measure the distance from that point to where the curve cuts the dotted line proceeding from it; this distance taken to the central line gives deviation 21½° W.

Ex. 3. What is the deviation for compass course N.E. ½ N., using the curve C?

Place one leg of a pair of dividers at N.E. ½ N. on the central line, and from thence measure the distance to the curve *in a direction exactly parallel* to the nearest dotted lines; this distance taken to the central line gives the deviation 12½° W., the deviation for N.E. ½ N.

Ex. 4. Find the deviation for Standard Compass Course N. 84° W., using deviation curve A.

Find N. 84° W. on the central line, and placing one foot of a pair of dividers on that point, from thence measure the distance in the direction of an imaginary line drawn parallel to the nearest dotted lines; apply this distance to the central line, which shows the deviation for the ship's course is 26½° W.

EXAMPLES FOR PRACTICE.

Required the deviation for each of the following compass courses, using (*a*) the curve A, and (*b*) the curve C:—

S.S.E.; N.E. by N.; N.W.; N.W. by N.; S.W. by W.; W.N.W.; South; N. 48° E.; S. 52° W.; E. by S. ½ S.; N. 41° W.; and S. 38° E.

NOTE.—Persons may differ one or two degrees in their estimate of what constitutes a fair curve; it is therefore quite likely that students may find their answers differ a degree or two from those given in this work.

308. We have now the following easily applied solution of the two following problems:—

Problem I.—From a **Compass Course,** to find the corresponding **Correct Magnetic Course.**

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309. Given the Standard Compass Course, to find the corresponding Correct Magnetic Course.

RULE XCI.

On the central line find the given Standard Compass Course, and move on the dotted *line drawn from it, or in a direction* parallel *to the* dotted *lines till you reach the curve, and then move on a* plain line, *or in a direction parallel to the* plain *lines, till you get back to the central line.* The point on the central line at which you arrive is the correct magnetic course required.*

NOTE.—The directions in the above rule are easiest done by means of a pair of dividers. To move on the *dotted* line, or in a direction parallel to it, place one leg of a pair of dividers on the course, and the other leg at that point on the curve which is intersected by the *dotted* line proceeding from the course, or a point on the curve where a line included between the leg of the dividers on the central line and the leg on the curve shall be *exactly parallel* to the nearest dotted lines, then to return to the central line—keep the first leg of the dividers fixed and lift the other off the curve, move in a direction *parallel to the plain lines* until you reach the central line; the point where the dividers cut the central line shows the correct magnetic course; or keep the leg of the dividers which is on the curve fixed, and move the other leg off the central line parallel to the plain line until it again cuts the central line, which indicates the correct magnetic course required.

EXAMPLES.

Ex. 1. The course steered by standard compass is N.N.E.: what is the correct magnetic course to lay down on the chart (using the curve C in the diagram, Plate I).

Find the given compass course N.N.E. on the central line, then take a pair of dividers, put one leg of the dividers on N.N.E., from which extend the other leg along the *dotted* line passing through the point till the curve is reached, then keeping the leg on the central line fixed, move the one off the curve, and then return to the central line in a direction parallel to the *plain* line; it will be found to intersect it at N. 13½° E., or N. by E. ¼ E., nearly, the required correct magnetic course.

Ex. 2. The course steered by compass is N.E. by N.: required the correct magnetic course (using curve A, plate I).

Follow the *dotted* line extending from N.E. by N. to where the curve cuts it, by placing one leg of a pair of dividers on the course found on the central line and the other at the point where the *dotted* passing through N.E. by N. cuts the curve, then keeping the leg on the central line fixed, lift the other from the curve and move in the direction of the nearest *plain* lines till the central line is reached; then the correct magnetic course will be found to be N. 52° E., or N.E. ¾ E., nearly.

Ex. 3. The course steered is S.S.W.: required the correct magnetic course (using curve C, plate I).

Place one leg of the dividers on the compass course S.S.W. on the central line and the other on the place where the *dotted* line proceeding from it is intersected by the curve, then keeping the leg on the central line fixed, return with the other leg to the central line in a direction parallel to the *plain* line, it will be seen that the *correct* magnetic course is S.W. ½ W.

Ex. 4. The course steered by compass is S.E. ½ E.: required the corresponding correct magnetic course (using curve C, Plate I).

Place one leg of the dividers on S.E. ½ E. on the central line, and the other leg on the curve, being careful to keep the two points of the dividers exactly parallel to the nearest *dotted* lines, then lift the leg off the curve and return to the central line, the place where this last line intersects the central line, shows the correct magnetic course to be S. 75½° E., or E. by S. ½ S.

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* It will be observed that this is merely the addition or subtraction, as the curve is to the right or left of the central line, of the deviation on the course, since the three sides of the triangle ABC passed over by the pencil or leg of dividers are all equal.

Ex. 5. Given the standard compass courses N. 38° E. and S. 49° W.: required the correct magnetic courses (using the A deviation curve, Plate I).

Place one leg of the dividers on the standard compass course N. 38° E. on the central line, and move the other leg out in a direction parallel to the nearest dotted line until it meets the curve; then, keeping the leg which is on the central line fixed, move the other leg in the direction of the *plain* lines until it returns to the central line. The point arrived at shows the *correct* magnetic course is N. 58° E., nearly, or N.E. by E. ½ E.

In a similar manner the correct magnetic course is found to be S. 33° W.

EXAMPLES FOR PRACTICE.

In each of the following examples the compass course is given, to find the corresponding *correct* magnetic course, using curve A and curve C.

Curve A.—N. 41° W.; N. 65° 30′ E.; S. 38° E.; S. 79° W.; West; N.E.; S.E. ½ E.

Curve C.—N. 39° W.; N. 48° E.; S. 50° E.; N. 78° W.; S. 76° E.; and S. 47° W.

Problem II.—From a given **Correct Magnetic Course** to find the corresponding **Compass Course.**

RULE XCII.

On the central line take the given correct magnetic course, and move on the plain *line drawn from that point or in a direction parallel to the* plain *lines till you arrive at the curve; and then move on a* dotted *line, or in a direction parallel to the* dotted *lines till you get back to the central line.* The point on the central line at which you arrive is the compass course required.*

See Note to Rule XCI, page 371.

EXAMPLES.

Ex. 1. Given correct magnetic course N.N.E., to find the corresponding compass course (using curve C).

Place one leg of the dividers on N.N.E. on the central line, extend the other leg to the spot where the *plain* line proceeding from N.N.E. meets the curve; then keeping the leg on the central line fixed, lift the one on the curve and return to the central line in a direction parallel to the *dotted* line, it will be found to intersect at N.E. by N., the required course by standard compass.

Ex. 2. What compass course will make correct magnetic S.E. (using curve A).

Find S.E. on the central line; place one leg of the dividers on the spot and the other leg on the curve where the *plain* line that passes through S.E. cuts the curve; then keep the leg that is on the central line fixed, lift the other leg off the curve and move it in the direction of the nearest dotted line till it again touches the central line; the compass course that makes *correct* magnetic S.E. is shown on the central line to be S. 67½° E., or E.S.E.

Ex. 3. It is found from the chart that the correct magnetic course from the ship's position at noon to the Start Point is N. 86° E. What course must be steered by Standard Compass (using curve C)?

Find the correct magnetic course N. 86° E. on the vertical line; place one foot of the dividers on the spot, then follow thence with the other leg in a direction parallel to the nearest *plain* line until it meets the curve, and then return with the other leg to the central line in a direction parallel to the *dotted* line; the compass course required is S. 69½° E.

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* To assist the memory the following rhyme is given in the Admiralty Manual:—

I.

"From compass course magnetic course to gain,
Depart by dotted and return by plain."

II.

"But if you wish to steer a course allotted,
Take plain from chart and keep her head on dotted."

Ex. 4. Required the compass course to make correct magnetic W. by N. (using curve A).

Place one leg of the dividers on W. by N. and the other on the curve where the *plain* line that passes through W. by N. cuts it; then keep the leg that is on the central line fixed, but lift the other off the curve and move it in the direction of the *dotted* line till it again touches the central line; it will then be seen that the compass course that makes *correct* magnetic W. by N. is N. 51° W., or N.W. ½ W.

Ex. 5. Given the correct magnetic courses N. 64° E. and N. 85° W., to find the Standard Compass course (using the C deviation curve, Plate I).

Find N. 64° E. on the central line; place one leg of the dividers on the point and the other on the curve, being careful to keep both legs of the dividers exactly parallel to the nearest *plain* line; keep the leg of the dividers that is on the central line fixed and move the other in the direction of the nearest *dotted* line till it meets the central line; the point of intersection in this instance is N. 85½° E.

In a similar manner the Standard Compass Course corresponding to correct magnetic course N. 85° W. is found to be S. 70° W.

EXAMPLES FOR PRACTICE.

In each of the following examples the correct magnetic course is given, to find the compass course (using curve A and curve C).

Curve A.—S. 73° 30′ W.; N. 42° 15′ E.; S. 15° 30′ W.; N. 14° 15′ E.; N. 62° 45′ E.; E. 15° S.; W. 45° S.; N.E. by N.; W.S.W.

Curve C.—S. 44° W.; N. 58½° E.; S. 50° E.; S. 22° W.; N.E. ½ E.

310. We shall now proceed to show the application of the foregoing rules to Questions 7, 8, 9, and 10, of List B, which contains the questions on the Deviation of the Compass required of Candidates for Certificates as Master Ordinary.

QUESTION 7. LIST B.

311. Given the **bearings** of a **distant object** *by Standard Compass* on eight *equidistant** points, to find the Correct Magnetic Bearing of the distant object,† and thence Deviation.

RULE XCIII.

1°. **If the Compass Bearings are all of the same name,** i.e., *if they are all* reckoned *from* N. *or* S., *towards* E. *or* W.:

> *Take the* sum *of the Bearings in each column, then* add *these sums together, and divide by* 8; *the* result *is the* Correct Magnetic Bearing of the distant object *of the* same name *as the* Standard Compass Bearings.

NOTE.—A bearing *North* or *South* must be expressed as 0°, whilst *East* and *West* bearing must be expressed as 90°, reckoned either from North or South (as most convenient) towards East or West; thus East may be written as N. 90° E., or as S. 90° E.; similarly West may be written either as N. 90° W. or S. 90° W.

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* The eight equidistant points are the four cardinal points and the four quadrantal points, viz., N.W., S.W., S.E., and N.E.

† The Correct Magnetic Bearing thus found is not strictly accurate; it will differ from the correct quantity by what is called the co-efficient A, if no heeling error be mixed up with the bearings given in the Table. The co-efficient A is found by adding the Deviations (algebraically),—that is, add together the Westerly deviations, also add the Easterly deviations together, and take the less from the greater, and mark the difference of the same name as the greater—and divide by 8. Experience and theory seem to show that a more satisfactory result may be obtained by a more simple process. Instead of adding the eight together and dividing by 8, add the bearings when ship's head at East and at West, and divide by 2; the result is the correct magnetic bearing required.

2°. **If the Compass Bearings be of different names :**

(a) *If* some *of the* Bearings *are reckoned from* North *and the* others *from* South:

Take either set *from* 180°, *and they will all be reckoned from the* same *point* North *or* South; the name *as to* East *or* West *remains unaltered;* add *all the bearings together and divide by* 8, *the result is the* correct magnetic bearing, *of the* same name *as the* unaltered bearings.

(b) *If* some *of the* Bearings *are towards the* East *and* others towards *the* West:

Find the sum *of those which are reckoned towards* East; *and also the* sum *of those which are towards the* West; *then take the* less *from the* greater, *and* mark *the* difference *of the* same name *as the* greater; *the result* divided *by* 8 *gives the* Correct Magnetic Bearing of the distant object, *which is of the* same name *as the* difference.

NOTE.—On the form given at the Marine Board Examinations there is not sufficient space to perform the last mentioned addition and division: there is only room to find the first two sums; the rest, however, can be finished in the margin.

3°. **To find the Deviation for each of the given Courses.—**

(a) If the Correct Magnetic *and* Compass *bearings are of* like *names:*

Take their difference.

(b) *If* one *is reckoned from* North *and the other from* South, first *take the Correct Magnetic Bearing from* 180°, *and the remainder will have the* same name *as the* compass bearing, *then take the* difference *between the* Correct Magnetic *and* Compass Bearings.

(c) *If* both *bearings are from* North *or* both *from* South, *but* one *is* towards East *and the* other towards West, *take their* sum:

The difference *or* sum will be the deviation.

4°. **To Name the Deviations.—***If the* Correct Magnetic Bearing *is to the* right *of the* Compass Bearing *the deviation is* East, *but if to the* left *it is* West.

EXAMPLE I.

In the following Table give the correct magnetic bearing of the distant object, and thence the Deviation.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 41° W.		South	S. 46° W.	
N.E.	S. 59 W.		S.W.	S. 25 W.	
East	S. 64 W.		West	S. 18 W.	
S.E.	S. 60 W.		N.W.	S. 23 W.	

NOTE.—The above is the form in which the Table is given at the Local Marine Board Examinations. The Table is printed, excepting the columns of Bearings, which the Examiner fills up in writing. The following is the above example worked :—

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 41° W.	1° E.	South	S. 46° W.	4° W.
N.E.	S. 59 W.	17 W.	S.W.	S. 25 W.	17 E.
East	S. 64 W.	22 W.	West	S. 18 W.	24 E.
S.E.	S. 60 W.	18 W.	N.W.	S. 23 W.	19 E.

S. 224° W. S. 112° W.
S. 112 W.
8)336
S. 42° W. = Correct magnetic bearing of distant object.

Here we first add together the eight given bearings of the distant object, making 336°, and divide the sum by 8, giving as the result S. 42° W., the correct magnetic bearing of the distant object.

We next take the difference between the correct magnetic bearing thus obtained and each bearing given in the table; thus, with the ship's head at North, the bearing by compass is S. 41° W., and the difference between this and the correct magnetic bearing S. 42° W. is 1°, and because the *correct magnetic* bearing is to the *right* hand of the standard compass bearing the deviation is East. Again, with the ship's head at N.E., the compass bearing is S. 59° W., and the difference between this and the *correct magnetic* bearing S. 42° W. is 17°, but now the correct magnetic bearing is to the left of the compass bearing, hence the deviation is West, and so on with the remaining bearings, and the work will stand as follows:—

Ship's Head.	N.	N.E.	East.	S.E.
Correct mag. bear.	S. 42° W.	S. 42° W.	S. 42° W.	S. 42° W.
Standard com. bear.	S. 41 W.	S. 59 W.	S. 64 W.	S. 60 W.
Deviation	1 E.	17 W.	22 W.	18 W.

Ship's Head.	S.	S.W.	West.	N.W.
Correct mag. bear.	S. 42° W.	S. 42° W.	S. 42° W.	S. 42° W.
Standard com. bear.	S. 46 W.	S. 25 W.	S. 18 W.	S. 23 W.
Deviation	4 W.	17 E.	24 E.	19 E.

NOTE.—In the above work, the deviations are obtained by subtracting the less bearing from the greater, because they are all of the same name. (See XCIII, 3° and 4°, page 374).

QUESTION 8. LIST B. (See Rule XCII, Problem II, page 372.

From the above table construct a NAPIER'S Curve, and give the courses you would steer by standard compass to make the following courses correct magnetic:—

(1.) S.E. (2.) N.E. ½ E. (3.) S. 10° W. (4.) E. ½ N.

To Construct the Curve from the Table.—With a pair of dividers take from the central line 1°, the deviation for ship's head North; and lay it off from North, on the central line along the dotted line passing through the given point, and towards the right—being East; at the extremity of the distance make a dot or cross. Next take 17° from the central line, and with one foot of the dividers on N.E. on the central line, lay off this distance on the dotted line passing through the given point and to the left, because the deviation is West. Proceed in like manner with the deviation 22° W. at East; with 18° W. the deviation at S.E.; and with 4° at W. the deviation at South. The deviation at S.W., West, and N.W. being easterly, must be applied to the right of the central line along the *dotted* lines proceeding from those points. Now draw with a pencil a curve passing as nearly as possible through the points found, and when satisfied with its uniformity, draw it in ink.

To find the Standard Compass Course.—(1.) Place one foot of a pair of dividers on S.E. on the central line, and the other foot on the point where the *plain* line extending from S.E. is cut by the curve; then keeping the first foot fixed and lift that on the curve, moving it in a direction parallel to the nearest *dotted* line, towards the central line; the compass course that makes *correct* magnetic S.E. is shown on the central line to be S. 29° E., or S.S.E. ¾ E., (easterly).

(2.) Take N.E. ¼ E. on the central line, then placing one foot of the dividers on that spot, extend the other foot from this point and parallel to the nearest *plain* line till it cuts the curve; then keeping the first foot fixed, move the one on the curve parallel to the nearest *dotted* line and towards the central line; the compass course that makes *correct* magnetic N.E. ¼ E. is shown on the central line to be E. by N. ¾ N.

(3.) Place one foot of the dividers on S. 10° W. on the central line, and extend the other foot parallel to the nearest *plain* line, and to the *right* until it meets the curve; then keeping the foot on the central line fixed, move the foot on the curve thence parallel to the nearest *dotted* line until it arrives at the central line, which shows that the compass course to be steered is S. 9° W., nearly, in order to make S. 10° W. correct magnetic.

(4.) One foot of the dividers being placed on E. ¼ N., move the other foot to the left from that spot and parallel to the nearest *plain* line until it is cut by the curve; from thence, keeping the first foot fixed on the central line, move parallel to the nearest *dotted* line till the central line is reached; the compass course that makes correct magnetic E. ¼ N. is shown on the central line to be S. 72° E.

QUESTION 9. LIST B.

Suppose you steer the following courses by the standard compass, find the correct magnetic courses from the curve drawn:—(See Problem I, Rule XCI, page 371).

(1.) S.S.E. ¾ E. (2.) S. ¾ W. (3.) E. by N. ¾ N. (4.) N. ¼ W.

(1.) **To find the Correct Magnetic Course.**—With one foot of the dividers on S.S.E. ¾ E. on the central line, move the other foot on a line to the *left* and parallel to the nearest *dotted* line until it cuts the curve; then keeping the first foot fixed, move the foot on the curve from thence parallel to the nearest *plain* one and towards the central line; the *correct* magnetic course is at once seen to be S. 45½° E.

(2.) Placing one foot of the dividers on S. ¾ W. on the central line, move the other foot on a line to the right, parallel to the nearest *dotted* line and cutting the curve; from thence, keeping the first foot fixed on the central line, move in a direction parallel to the nearest *plain* line until the central line is reached; the *correct* magnetic course is thus shown to be S. 10° W.

(3.) Take the point on the central line representing E. by N. ¾ N., place a leg of the dividers on that point and move the other leg in a direction parallel to the *dotted* lines, and after meeting the curve, return parallel to the *plain* lines, until the central line is again reached; the correct magnetic course is thus found to be N. 48¾° E.

(4.) One leg of the dividers being fixed on N. ¼ W. found on the central line, move the other leg in a direction parallel to the *dotted* lines till the curve is reached; and from thence returning to the central line in a direction parallel to the *plain* lines, we find *correct* magnetic course is North.

QUESTION 10. LIST B.

312. Given the Bearings of two (or more) distant objects by the Standard Compass and also the Azimuth of the Ship's Head: required the correct magnetic bearing of these objects.

RULE XCIV.

1°. *Find the* Deviation *corresponding to the* direction of the ship's head, *taking it from the Napier's Deviation Curve with a pair of dividers.*

2°. *Apply the* Deviation *thus found* (keeping the legs of the dividers the same distance apart) *to the Bearing of distant object by Standard Compass,* thus—*Place one leg of the dividers on the part of the central line which represents the Standard Compass Bearing,* and lay the other leg on the central line.

Upwards if deviation for ship's head is W.
Downwards if deviation for ship's head is E.

The number of degrees *there indicated will be the* correct magnetic bearing *from* N. *or* S. *towards the* E. *or* W.

The following bearings of distant objects have been taken by the Standard Compass as above; with the ship's head as given, find the correct magnetic bearing.

	Ship's Head.	Compass Bearing.		Ship's Head.	Compass Bearing.
1.	West	East.	3.	E. ¾ N.	N. ¾ W.
2.	S.S.E.	E. by S. ¼ S.	4.	N.E. ¼ E.	W. ¼ S.

On the central line find the given course, West, and with a pair of dividers measure the distance from the point to where the curve cuts the *dotted* line proceeding from the course; this distance taken to the central line gives deviation 24° E. for ship's head at West.

We next apply the deviation to East—the bearing of distant object by standard compass —by placing one leg of dividers on central line at East and laying the other leg on the central line *downwards* (the deviation being East), the number of degrees there indicated; whence the correct magnetic bearing of distant object is S. 66° E.

Again, ship's course S.S.E. is found on the central line; with dividers measure from thence to where the *dotted* line proceeding from given course is cut by the deviation curve; this distance, taken from the central line, gives deviation 13° W.

The standard compass bearing of distant object taken when ship's head was at S.S.E. is E. by S. ¼ S., or S. 76° E., to which apply deviation, found as above, by placing one leg of dividers on S. 76° E. on the central line, and applying the other leg *upwards* on the central line (deviation being West); the result is the correct magnetic bearing S. 89° E.

The deviation due to E. ¾ N.—the direction of the ship's head—is found on deviation curve to be 22½° W.

Apply this deviation to compass bearing N. ¾ W., or N. 8° W., *upwards* on the central line (deviation being West), which gives correct magnetic bearing of distant object N. 30½° W.

N.E. ¼ E. is the next given direction of the ship's head, and applied to the central line, the deviation for which on curve is found to be 18° W.

The deviation thus found being applied *upwards* from W. ¼ S., or S. 87° W., gives the correct magnetic bearing of distant object S. 69° W.

EXAMPLE II.

I. In the following Table give the correct magnetic bearing of the distant object, and thence the Deviation:—

(Correct Magnetic Bearing of distant object = N. 89° 4′ W.)

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 87° W.	3° E.	South	N. 87° W.	2° W.
N.E.	S. 70 W.	21 E.	S.W.	N. 75 W.	14 W.
East	S. 71 W.	20 E.	West	N. 68 W.	21 W.
S.E.	S. 81 W.	10 E.	N.W.	N. 72 W.	17 W.

S. 310° W. N. 302° W.
S. 418 W. (180 × 4) = 720
8)728 S. 418 W.
S. 91 W. = Correct magnetic bearing.
180
or N. 89 W.

In this example the bearings given in the left hand column are reckoned from S. towards W., while the bearings in the right hand column are reckoned from N. towards W.; therefore, before adding up the latter column, each bearing must be subtracted from 180°, and the remainder, in each case, is the bearing reckoned from S. towards W.

Subtracting N. 87° W. from 180° = S. 93° W. which put in the place of N. 87° W.
N. 75 W. „ 180 = S. 105 W. „ „ N. 75 W.
N. 68 W. „ 180 = S. 112 W. „ „ N. 68 W.
N. 72 W. „ 180 = S. 108 W. „ „ N. 72 W.

We may, however, proceed as above, viz.:—add up the Bearings reckoned from N. towards W.; and since there are four bearings so reckoned (from N. towards W.); take the sum from 720 (180 × 4); the remainder is the sum of the bearings to be reckoned from S. towards W. It is evident that to subtract the sum of the *four* bearings from 720° is the same thing as to subtract each bearing from 180° and to add the remainders.

Ship's Head.	N.	N.E.	East.	S.E.
Correct mag. bearing	S. 91° W.	S. 91° W.	S. 91° W.	S. 91° W.
Compass bearing	S. 88 W.	S. 70 W.	S. 71 W.	S. 81 W.
Deviation	3 E.	21 E.	20 E.	10 E.
Ship's Head.	S.	S.W.	West.	N.W.
Correct mag. bearing	N. 89° W.	N. 89° W.	N. 89° W.	N. 89° W.
Compass bearing	N. 87 W.	N. 75 W.	N. 68 W.	N. 72 W.
Deviation	2 W.	14 W.	21 W.	17 W.

II. From the above Table construct a Napier's curve, and give the courses you would steer by standard compass to make the following courses correct magnetic:—

(1.) W. by S. ¾ S. (2.) N. ½ E. (3.) E. ¾ N. (4.) S.E. ¾ S.
Answers:—(1.) West. (2.) N. 1° E. (3.) N. 60° E. (4.) S. 49° E.

Note.—For the method of constructing the curve, see No. 305, page 367, and for rule to find standard compass course to steer, see Rule XCII, page 372.

III. Suppose you steer the following courses by standard compass, find the correct magnetic courses from the curve drawn:—

(1.) North. (2.) S.S.W. ¼ W. (3.) E. by S. ¼ S. (4.) N.E. ½ E.
Answers:—(1.) N. 3° E. (2.) S. 15° W. (3.) S. 59° E. (4.) N. 71° E.

IV. You have taken the following bearings of a distant object by your standard compass as above; with the ship's head as given, find the correct magnetic bearing.

Ship's Head.	Compass Bearings.	Ship's Head.	Compass Bearings.
S. ¾ W.	South.	N.N.E. ¾ E. ..	S.W. ½ S.
N.W. by W. ..	E. ¾ N.	S.E.	E. ½ S.

By the curve the deviation for ship's head S. ¾ W. is 5½° W.; then placing one leg of the dividers on compass bearing South on central line, and laying the other leg *upwards* (deviation being West), the correct magnetic bearing of distant object is found to be S. 5½° E.

The deviation by the curve for ship's head N.W. by W. is 17° W.; then placing one leg of the dividers on the part of central line representing compass bearing E. ¾ N., the other leg applied *upwards* on the central line intersects it at N. 63° E.: what is the correct magnetic bearing?

For position of ship's head N.N.E. ¾ E. the deviation by the curve is 18½° E.; placing one leg of the dividers on the compass bearing S.W. ½ S., and laying the other leg *downwards* (deviation being East) it shows the correct magnetic bearing to be S. 60½° W.

Ship's head S.E. gives on curve deviation 10½° E.; one leg of dividers placed E. ½ S. and the other leg applied *downwards* (deviation being East) gives on central line correct magnetic bearing S. 76½° E.

EXAMPLE III.

QUESTION 7. LIST B.

I. From the following Table find the correct magnetic bearing of the distant object, and thence the deviation:—

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 1° E.		South	N. 3° W.	
N.E.	N. 13 W.		S.W.	N. 1 E.	
East	N. 15 W.		West	N. 9 E.	
S.E.	N. 8 W.		N.W.	N. 12 E.	

In this example some of the bearings are towards East and the others towards West; we therefore write down in one column those which are reckoned towards East, and add these up; we likewise write down in another column those which are reckoned towards West, and add up this column; the less sum being subtracted from the greater gives as a remainder N. 16° 0′ W., which divided by 8 gives N. 2° W. for the correct magnetic bearing: the work will stand thus:—

Ship's Head.	Compass Bearings.	Ship's Head.	Compass Bearings.
North	N. 1° E.	N.E.	N. 13° W.
S.W.	N. 1 E.	East	N. 15 W.
West	N. 9 E.	S.E.	N. 8 W.
N.W.	N. 12 E.	South	N. 3 W.
	N. 23 E.		N. 39 W.
			N. 23 E.
			8) N. 16 W.

Correct magnetic bearing is N. 2 W.

The deviation for each position of the ship's head is next to be found, and we proceed as follows:—

Ship's Head.	North.	N.E.	East.	S.E.
Correct magnetic bearing	N. 2° W.	N. 2° W.	N. 2° W.	N. 2° W.
Compass bearing	N. 1 E.	N. 13 W.	N. 15 W.	N. 8 W.
Deviation	3 W.	11 E.	13 E.	6 E.

Ship's Head.	South.	S.W.	West.	N.W.
Correct magnetic bearing	N. 2° W.	N. 2° W.	N. 2° W.	N. 2° W.
Compass bearing	N. 3 W.	N. 1 E.	N. 9 E.	N. 12 E.
Deviation	1 E.	3 W.	11 W.	14 W.

QUESTION 8. LIST B.

From the above Table construct a NAPIER's curve, and give the courses you will steer by standard compass to make the following courses, correct magnetic.

1.	N.E. ½ E.	2.	W.S.W.	3.	N.N.W.	4.	S.S.E.
5.	N.N.E.	6.	S. 18¾° W.	7.	N. 4° E.	8.	S. 62½° E.

NOTE.—For the method of constructing the curve, see No. 305, page 367, and for Rule for finding standard compass courses to steer, see Problem II, Rule CXII, page 372.

Answers.—	1.	N. 40° E.	2.	S. 76° W.	3.	N. 14½° W.	4.	S. 26° E.
	5.	N. 18 E.	6.	S. 19 W.	7.	N. 5 E.	8.	S. 73 E.

QUESTION 9. LIST B.

Suppose you steer the following courses by the standard compass, find the correct magnetic courses from the curve drawn :—

1.	E. by S. ½ S.	2.	E. ¾ N.	3.	S. 85° W.	4.	N. 1° E.

For the Rule for working this Question, see Problem I, Rule XCI, page 371.

Answers.—	1.	S. 65½° E.	2.	N. 84½° E.	3.	N. 74½° W.	4.	N. 1½° W.

QUESTION 10. LIST B.

You have taken the following bearings of distant objects by your standard compass as above, with the ship's head as given, find the correct magnetic bearings. (See Rule XC, page 370).

Ship's Head.	Compass Bearing.	Ship's Head.	Compass Bearing.
S.E. by E.	N. 68° E.	S.S.W. ½ W. ..	N. 4° E.
W. ¼ N.	S. 54 W.	N. ¾ E.	South.

The deviation by curve for ship's head S.E. by E. is 7½° E., and the correct magnetic bearing corresponding to N. 68° E. is found to be N. 75½° E.

Ship's head W. ¼ N. gives on curve the deviation 11° W., whence the correct magnetic bearing corresponding to compass bearing S. 54° W. is found to be S. 43° W.

Ship's head S.S.W. ½ W. gives deviation 1½° W. on the curve, and the correct magnetic bearing corresponding to compass bearing N. 4° E. is found to be N. 2½° E.

Ship's head N. ¾ E. gives on curve the deviation 0, whence the correct magnetic bearing is South—the same as the compass bearing.

EXAMPLES FOR PRACTICE.

EXAMPLE I.

I. From the following Table find the correct magnetic bearing of the distant object, and thence the deviation :—

(S.S. *B*———. Heeling 10° to Port.)

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 77° W.		South	S. 76° W.	
N.E.	W. 1 S.		S.W.	W. 12 N.	
East......	W. 19 S.		West	W. 19 N.	
S.E.......	S. 62 W.		N.W.	N. 72 W.	

Answer.—Correct magnetic bearing, West, or S. 90° W.

In such a case as this, where the bearings are near the East or West points, and are given from different points, they must all be expressed from either the North or South point by taking their equivalents as follows, where they are all expressed for the North point.

The first bearing is expressed from the North towards the West. The second bearing is expressed from the West towards the South, but by adding 90° we get the equivalent bearing N. 91° W.; similarly, the third bearing becomes N. 109° W. The fourth bearing S. 62° W. is taken from 180°, and this becomes N. 118° W., and the fifth bearing is also taken from 180°, and the equivalent bearing is thus found to be N. 104° W. The sixth and seventh bearings being reckoned from W. to N., subtracting each from 90°, whence we get N. 78° W. and N. 71° W. as the respective equivalent bearings. The last bearing being N. 72° W., is written down as it stands, unchanged.

Answer:—Deviations—1. 13° W. 2. 1° E. 3. 19° E. 4. 28° E. 5. 14° E. 6. 12° W. 7. 19° W. 8. 18° W.

II. From the above Table construct a NAPIER's curve, and give the courses you would steer by the standard compass to make the following courses correct magnetic:—

1. N.E. ¼ N. 2. E. by S. ½ S. 3. S.S.W. ¼ W. 4. N.N.W. ¼ W.
Answer:—1. N. 42° E. 2. N. 87° E. 3. S. 28° W. 4. N. 10° W.

III. Given the following courses steered by standard compass to find the correct magnetic courses from curve drawn:—

1. N. by E. ½ E. 2. S.S.E. ½ E. 3. W. ¼ S. 4. W. by N. ¾ N.
Answer.—1. N. 6½° E. 2. S. 2° E. 3. S. 69° W. 4. N. 89° W.

IV. You have taken the following bearings of distant objects by your standard compass with the ship's head S.E. by E. ½ E.: find the correct magnetic bearing.

Standard compass bearings:—W. by N. ¼ N. and N. ¼ W.

Answer.—Deviations:—1. 26° E. 2. 20° W.

Correct magnetic bearings:—1. N. 51° W. 2. N. 18° W.

EXAMPLE II.

I. From the following table find the correct magnetic bearing of the distant object and thence the deviation:—

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 42° W.		South	N. 44° W.	
N.E.	N. 17 W.		S.W.	N. 68 W.	
East......	N. 9 W.		West	N. 76 W.	
S.E.......	N. 17 W.		N.W.	N. 64 W.	

Answer:—Correct magnetic bearing N. 42° W.

Deviations 0°; 25° W.; 33° W.; 25° W.; 2° E.; 26° E.; 34° E.; 22° E.

II. From the above table construct a NAPIER's curve and give the courses you would steer by standard compass to make the following courses correct magnetic:—

1. N.W. ½ W. 2. S.E. ½ S. 3. E. ¼ S. 4. W. ¾ S.
Answer:—1. N. 84° W. 2. S. 24° E. 3. S. 58° E. 4. S. 53½° W.

III. Suppose you steer the following courses by standard compass, find the correct magnetic courses from the curve drawn:—

1. W. by N. ¾ N. 2. South. 3. E. by N. ¼ N. 4. N. by E. ¾ E.
Answer:—1. N. 39° W. 2. S. 1½° W. 3. N. 43½° E. 4. N. 7° E.

IV. You have taken the following bearings of distant objects by your standard compass as above; with the ship's head as given, find the correct magnetic bearing:—

Ship's Head	Bearing of Distant Object by Standard Compass.	Ship's Head.	Bearing of Distant Object by Standard Compass.
S.E.	N. by E. ¼ E.	W. by S. ¾ S. ...	E. ½ N.
E. by S.	N. by W. ¾ W.	N.E. ½ E.	S.W. ¾ S.

Answer:—Deviations for S.E. is 25° W.; for E. by S. is 32° W.; for W. by S. ¾ S. is 32° E.; N.E. ½ E. is 26½° W.

Correct magnetic bearings N. 80° W.; N. 52° W.; S. 64° E.; S. 10° W.

EPAMPLE III.

I. From the following table find the correct magnetic bearing of the distant object, and thence the deviation:—

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 13° W.		South	N. 23° W.	
N.E.	N. 35 W.		S.W.	N. 2 W.	
East......	N. 41 W.		West	N. 5 E.	
S.E.	N. 35 W.		N.W.	North.	

Answer:—Correct magnetic bearing N. 18° 6′ W.

Deviations:—5° W.; 17° E.; 23° E.; 17° E.; 5° E.; 16° W.; 23° W.; 18° W.

II. From the above table construct a NAPIER's curve, and give the courses you would steer by standard compass to make the following courses correct magnetic:—

1. N. ½ W.	2. E. ½ S.	3. N.W. by W. ½ W.	4. W. ½ S.
Answer:—1. North.	2. N. 73° E.	3. N. 44° W.	4. N. 71° W.

III. You have steered the following courses by standard compass: find the correct magnetic courses from the curve drawn:—

1. E. ½ N.	2. S.E. ¾ E.	3. N. ¾ W.	4. S.W. ½ S.
Answer:—1. S. 72½° E.	2. S. 35° E.	3. N. 16½° W.	4. S. 27° W.

IV. You have taken the following bearings of distant objects by your standard compass; with the ship's head as given below, find the correct magnetic bearing:—

Ship's Head.	Bearing of Distant Object by Standard Compass.	Ship's Head.	Bearing of Distant Object by Standard Compass.
S.W. ½ S.	E. ¾ S.	N.E. ¼ N.	W. ¼ S.
North	S.E. ¾ S.	E. by S. ½ S. ..	E. ¼ S.

Answer:—Deviations:—14° W.; 5° W.; 16° E.; 22° E.

Correct magnetic bearings, N. 84° E.; S. 42° E.; N. 77° W.; S. 65° E.

EXAMPLE IV.

I. From the following Table find the correct magnetic bearing of the distant object, and thence the deviation:—

(S.S. *Royal Charter*, before compensation).

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 81° E.		South	N. 16° E.	
N.E.	N. 79 E.		S.W.	N. 2 E.	
East	N. 68 E.		West	N. 8 E.	
S.E.	N. 48 E.		N.W.	N. 51 E.	

Answer:—Correct magnetic bearing N. 44° E.

Answer.—Deviations:—1. 37° W. 2. 35° W. 3. 24° W. 4. 4° W. 5. 28° E. 6. 42° E. 7. 36° E. 8. 7° W.

II. From the above Table construct a NAPIER'S curve, and give the courses you would steer by standard compass to make the following courses correct magnetic:—

1. E. ½ N. 2. N. ¾ W. 3. S. by W. ½ W. 4. W. ½ N.

Answer:—1. S. 77° E. 2. N. 29° E. 3. S. 7° E. 4. S. 53° W.

III. Suppose you steer the following courses by standard compass, find the correct magnetic courses from the curve drawn:—

1. N.E. ½ E. 2. S.E. ½ S. 3. South. 4. W. ½ S.

Answer:—1. N. 16½° E. 2. S. 39½° E. 3. S. 28° W. 4. N. 57° W.

IV. You have taken the following bearings of distant objects by your standard compass as above; with the ship's head N. by E. ½ E., find the correct magnetic bearings.

Standard compass bearings:—S.W. ½ W. and S. ¾ E.

Answer.—Deviation:—39° W. Correct magnetic bearings:—S. 11½° W. and S. 47½° E.

EXAMPLE V.

I. From the following table find the correct magnetic bearings of the distant object, and thence the deviation. (S.S. *Royal Charter*, after compensation).

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 88° E.		South	S. 82° E.	
N.E.	South.		S.W.	S. 86 E.	
East......	S. 88 E.		West	S. 88 E.	
S.E......	S. 83 E.		N.W.	S. 84 E.	

Answer:—Correct magnetic bearing S. 86° E.

Answer.—Deviations:—1. 2° E. 2. 4° E. 3. 2° E. 4. 3° W. 5. 4° W. 6. 0°. 7. 2° E. 8. 2° E.

II. Given the correct magnetic course, to find the courses to steer by standard compass:—

1. W. ¼ N. 2. S.W. ¼ S. 3. E. by S. ½ S. 4. N.N.E. ¼ E.

Answer.—1. N. 89° W. 2. S. 42° W. 3. S. 73° E. 4. N. 22½° E.

III. Given courses by standard compass, to find correct magnetic:—

1. N. by W. ¾ W. 2. W. by N. ¾ N. 3. S. ¼ E. 4. E. by N. ¼ N.

Answer.—1. N. 20° W. 2. N. 70° W. 3. S. 7½° W. 4. N. 78° E.

IV. You have taken the following bearings of distant objects by standard compass with ship's head as given below, find correct magnetic bearing:—

Ship's head S.S.E. ½ E., compass bearings S. ½ W. and N.E. by E. ½ E.

Correct magnetic bearings:—S. 1° W. and N. 57½° E.

EXAMPLE VI.

I. From the following table find the correct magnetic bearing of the distant object, and thence the deviation. (S.S. *Royal Charter*, at Melbourne).

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 62° W.		South	W. 15° N.	
N.E.	W. 24 S.		S.W.	N. 81 W.	
East......	W. 7 S.		West	W. 5 S.	
S.E.......	N. 77 W.		N.W.	S. 67 W.	

Answer:—Correct magnetic bearing S. 83¾° W. = S. 84° W.

Deviations:—22° E.; 18° E.; 1° E.; 19° W.; 21° W.; 15° W.; 1° W.; 17° E.

II. From the above table construct a NAPIER's curve, and give the course you would steer by standard compass to make the following courses correct magnetic:—

1. N. ½ E. 2. S. ½ W. 3. E. ¼ S. 4. N.E. ½ E.

Answer.—1. N. 16° W. 2. S. 25° W. 3. S. 86° E. 4. N. 29½° E.

III. You have steered the following courses by standard compass; find the correct magnetic courses from the curve drawn:—

1. N.E. ½ N. 2. S.E. ½ S. 3. W. ¼ N. 4. N.W. ½ N.

Answer.—1. N. 59° E. 2. S. 59° E. 3. N. 87° W. 4. N. 21° W.

IV. You have taken the following bearings of distant objects by your standard compass as above; with the ship's head by standard compass N. ½ W., find the correct magnetic bearing.

Bearings of distant object by standard compass S.S.E. ¼ E. and E. ½ N.

Answer.—Deviation 23° E. Correct magnetic bearings:—S. 2½° E. and S. 73° E.

ON REVOLVING STORMS.

Of late years attention has been directed to those violent storms which occur at certain periods of the year in low latitudes, and are called Hurricanes in the West Indies and Southern Indian Ocean, Cyclones in the Northern Indian Ocean and other places, and Typhoons in the China Sea.

The examination of the logs of ships that have encountered these tempests, and of the accounts received from places exposed to them, have established two facts—1, that cyclones or revolving storms are atmospheric disturbances by virtue of which large masses of air are indued with a rapid rotatory motion round an axis more or less vertical, and—2, at the same time carried forward with a considerable velocity in a parabolic orbit. The latest inquiries bearing on this head acquaint us with the very important fact that there are two kinds of these destructive storms, viz., cyclones, or revolving storms, and *spirals* or *incurving* storms.*

Order of Rotation.

In N. lat. *against* watch hands, in S. lat. *with* watch hands.

The direction of the revolution is in N. latitude from right to left, or against the hands of a watch: in S. latitude the rotatory motion is from left to right, or with the hands of a watch: the observer being supposed to look from the centre of the revolving storm towards its circumference: in other words, in both hemispheres the air in either kind of storm *revolves* or *incurves* AGAINST the sun, that is, *contrary to the apparent course of the sun.*

The curve which the wind describes is in reality a spiral around the focus. If these are drawn, that for the northern hemisphere would be curved in the same direction as the figure 6 (see Fig. 94); for the southern hemisphere it would be this figure reversed, or like the figure 6 on the back of the paper, both beginning at the top (see Fig. 95).

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* Both Redfield, Reed, and Piddington believed that the air did incurve towards the centre of a hurricane, (see page 108, par. 120 of "Piddington's Horn Book,") to the extent of two points or more; this incurvature or in-draft is now a well known fact; every modern writer on the subject—Meldrum at the Mauritius—Blandford and Wilson in India—Wojeikof, Mohn, and Hildebrandson on the continent—and Scott, Buchan, and Ley at home, with many other meteorologists of note adopt the view of a spirally incurving movement as the most probable behaviour of the wind in cyclones and hurricanes.

Fig. 94.
North Latitude.

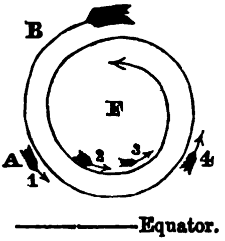
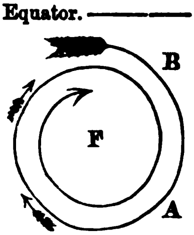


Fig. 95.
South Latitude.



Incurving Storm Ley Type.

Meldrum Type.

The departure from a true circular movement of the wind in a northern storm progressing towards the North-east (according to Rev. Clement Ley) is shown in Fig. 96, the incurvature being but slight in the hinder part of the storm, but rather considerable in the advancing semicircle. Fig. 97 represents the reverse of Meldrum's incurving storm in the southern hemisphere, when taken as a type of a similar storm in the northern hemisphere.

Fig. 96.

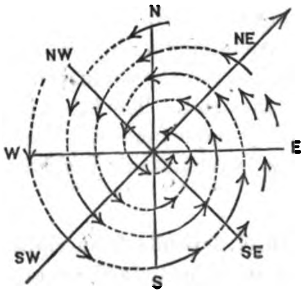
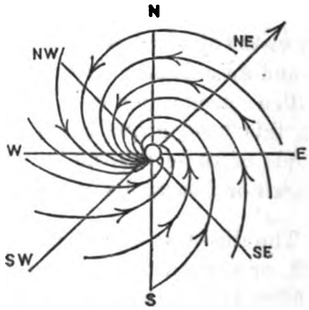


Fig. 97.



It is customary to ennunciate the general law of the rotatory theory as above (page 385), viz., by saying that in N. latitude the revolution of the storm is from right to left, or against the hands of a watch, and in S. latitude with the hands of a watch. But it sometimes happens that from not fully comprehending the facts of the case the observer may suppose that the law does not hold good in all cases. For instance, if the position of the observer be on the northern side of the path of the storm, he is first taken by the N.W. edge of the cyclone with the wind at N.E. As the storm passes over him the wind successively changes through E.N.E., E., to E.S.E., and finally leaves him at S.E. The wind apparently revolving in exactly the opposite direction to that just stated. Hence it may be inferred that in this instance the theory fails. But the mistake arises from not perceiving that when it is stated, that in N. latitude the storm revolves against the hands of a watch, and in S. latitude with them, the observer is supposed to be standing as it were externally to the storm, viewing its general features: the apparent changes in the direction of the wind, noticed by a spectator, within the storm, as it sweeps past him, being only coincident with the motion of revolution of the whole storm on the *South* side of the path of the focus in the northern hemisphere, and on the *North* side of the path of the focus in the southern hemisphere.

Deductions from the order of Rotation.

Each portion of the hurricane has its appropriate wind.

Putting the progressive motion out of the question for a moment, the rotation of the air in a revolving storm or cyclone enables us to characterise certain portions of the storm by certain hurricane winds; and upon dividing the storm by diameters drawn from the northern to the southern, and from the eastern to the western margins, we find that, in the northern hemisphere, on the northern margin, the wind will be *easterly;* on the eastern margin, *southerly;* on the southern margin, *westerly;* and on the western margin, *northerly;* and a person finding himself at the upper extremity of the northern diameter, if supposed to pass over the circumference of one of the rings from the North to the South through East, the shift of winds he will experience will be East, E. by S., E.S.E., S.E. by E., and so on to West. If he moves from North to South through West the shifts will be East, E. by N., E.N.E., N., N. by W., N.N.W., and so on to West. In the former case the winds will change in the same direction as the hands of a watch, and in the latter case in the opposite direction. (See Figs. 98 and 99).

Fig. 98.

N. Hemisphere.

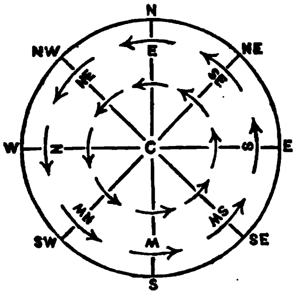
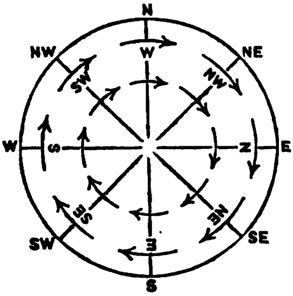


Fig. 99.



S. Hemisphere.

The relations of the wind to the margins in S. lat. exactly the reverse of those in N. lat.

In the Southern Hemisphere the relations of the wind to the margins will be exactly the reverse of their relations in the northern, owing to the reversion of the rotation; thus it is the southern margin of the storm in south latitude, that exhibits an *easterly*, the western margin a *southerly*, the northern margin a *westerly*, and the eastern margin a *northerly* wind, and a person at the northern extremity of the North and South diameter will be exposed to a West wind, and his shift of winds in moving from North to South through East will be West, W. by N., W.N.W., N., N. by E., N.N.E., to East, or the shift of winds will be in the opposite direction to that of the motion of the hands of a watch, and will be in the same direction as this motion as he moves from North to South through West.

At that part of the revolving storm which is nearest the equator, the wind is from the west in both N. and S. latitudes; and at that point which is furthest from the equator, the wind is from the East.

The winds on the radii similar to the winds on the margins terminating them.

If the area covered by the storm be divided into four quadrants by diameters drawn from the northern to the southern margins, and from the eastern to the western margins, the winds on each of the radii will be similar to the winds characterising the margins terminating them, thus in the radius N C (Fig. 98) northern hemisphere, the wind is East; on E C, South; on S C, West; and on W C, North.

Marginal winds reversed in S. lat., radial winds the same as marginal winds.

As the marginal winds are reversed in the southern hemisphere and the radial winds are in all cases the same as the marginal winds, so in the radius N C (Fig. 99) southern hemisphere, the wind will be West; on E C, North; on S C, East; and on W C, South.

The bearing of the storms centre eight points *with the sun.*

From the foregoing there results a very simple *rule for determining the bearing of the centre* of the storm from the ship, viz., *look to the wind's eye and set its bearing by compass*, the EIGHTH *point to the* RIGHT thereof when in the NORTHERN HEMISPHERE, but the LEFT of the *direction of the wind in the* SOUTHERN HEMISPHERE will be the focus or centre of the storm.

Thus, in N. latitude from an *easterly* wind which characterises the northern margin of the storm its centre will bear *South;* from a *northerly* wind the centre will bear *East;* from a *westerly* wind it will bear *North;* and from a *southerly* wind *West* (see Fig. 98).

But in S. latitude from an *easterly* wind, the centre of the storm bears *North;* from a *southerly* wind the centre bears *East;* from a *westerly* wind *South;* and from a *northerly* wind *West* (see Fig. 99).

Nothing can be more unambiguous than the above rule, but to prevent the possibility of applying the eight points on the wrong side two tables are added, one for N. latitude and the other for S. latitude, in which the seaman will see the question solved without the trouble of any reflection.

IN THE NORTHERN HEMISPHERE.		IN THE SOUTHERN HEMISPHERE.	
If the wind be	The centre of the storm will bear from the ship	If the wind be	The centre of the storm will bear from the ship
North	East	North	West
N.N.E.	E.S.E.	N.N.E.	W.N.W.
N.E.	S.E.	N.E.	N.W.
E.N.E.	S.S.E.	E.N.E.	N.N.W.
East............	South	East............	North
E.S.E..........	S.S.W.	E.S.E..........	N.N.E.
S.E.	S.W.	S.E.	N.E.
S.S.E.	W.S.W.	S.S.E.	E.N.E.
South	West	South	East
S.S.W.	W.N.W.	S.S.W.	E.S.E.
S.W.	N.W.	S.W.	S.E.
W.S.W.	N.N.W.	W.S.W.	S.S.E.
West	North	West	South
W.N.W..........	N.N.E.	W.N.W..........	S.S.W.
N.W.	N.E.	N.W.	S.W.
N.N.W.	E.N.E.	N.N.W.	W.S.W.

To those who prefer it, the rule just enunciated may be put in another form, viz.: *the focus or centre of a revolving storm* bears EIGHT *points from the direction of the wind at the ship, reckoned* with the apparent course of the sun; and this obtains in both hemispheres, for the rotation being reversed with the course of the sun, the bearing of the centre remains the same.

Thus, in (Fig. 98) N. latitude, a ship on the radius C—N.E. has the centre bearing S.W., the wind being S.E., while in S. latitude (Fig. 99) a ship on the same radius will still have the centre bearing S.W., but the wind will blow from N.W.; which is also in accordance with the deduction that the centre bears eight points from the wind, reckoned with the sun.

Thus from the direction of the wind *only*, in a revolving storm, two very important points may be determined, the exact position of the ship in a storm or hurricane, and the bearing of the centre of the storm from the ship.

These storms occur in all the great oceans, with the exception of the South Atlantic. In the North Atlantic the stormy area may be said to be comprised within the parallels of 10° and 50° of North latitude, and 30° and 105° of West longitude. Of this immense area the meridians of 50° and 90° include the greatest number of storm paths; the points of recurvature occurring about 80° W. and 30° N. The hurricane region South of the equator extends more or less over the entire area of the S.E. trades in the Indian Ocean, from the coast of Australia as far as Madagascar, between the lats. 6° S. and 40° S. In the Persian Gulf and Bay of Bengal they are to be found extending northward from latitude 10° N.; in the China Sea, between the latitude of 12° or 15° N. as far as 50° N., but generally not beyond long. 140° E., and the North and South Pacific Oceans are not exempt from their ravages. Storm Areas.

Though these storms in traversing the ocean do not always adopt exactly the same path, nor ever travel with any uniform velocity, yet there is so much apparent similarity in their movements as to show that they are ruled by one general law. To endeavour to trace this law, the log books of a great number of vessels, in all parts of the sea, have been examined, as well as the meteorological registers of numerous places on shore; and from them the movements of these storms have been reduced into comparative tables, their separate tracks graphically represented on charts, and their several characteristics analysed with great labour. The general results may be thus briefly stated:— Paths.

Commencing to the East, at a point a few degrees North of the equator (about 10° to 12° N.),* the progressive motion of the storm in N. latitude is first bodily to the West, very soon slightly North of West, as it approaches 20° N. its course is more or less towards N.W., at 30° N. it recurves* so as to change its direction—as afterwards to progress to the N.E.—increasing in diameter, while the wind, still of fearful violence, has somewhat diminished in force as compared with its rotatory velocity while within the tropics, and so it moves onward until it breaks up (see Fig. 100).

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* The origin of those hurricanes, which prevail on the Atlantic Coast, appears to be at the southern limit of the northern trade wind, or in the latitude of 10° or 12° N.

Fig. 100.
NORTHERN HEMISPHERE

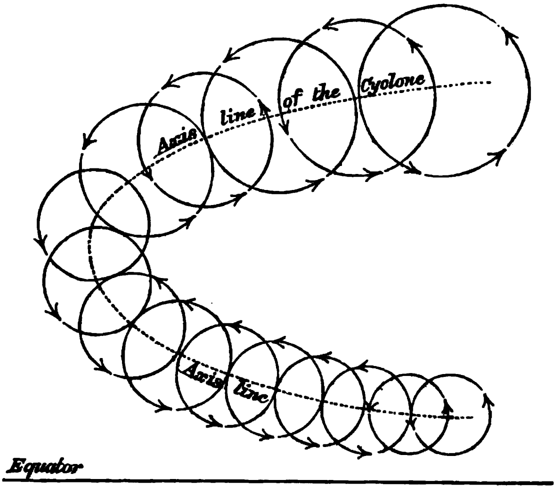
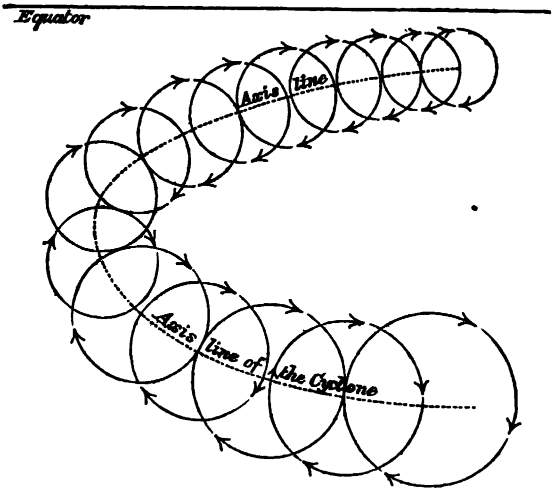


Fig. 101.
SOUTHERN HEMISPHERE



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* Revolving storms are liable to *recurve* in all latitudes from 10° to 40° N., but mostly about 30° N.

In S. latitude the path of the entire body of the storm commences about 10° S. of the equator, is first West, very soon a little inclined to the South of West, and gradually towards S.W.; at about 25° S. it recurves* or turns to the S.E., expanding in dimensions and probably diminishes in force as it traverses the extra-tropical regions until it finally disappears (see Fig. 101).

There is no part of the subject, however, on which the information we have is so limited and uncertain as the habitual tracks of these tempests. They seem to vary much according to the month in which they occur, and in various parts of the world, being greatly influenced by local circumstances, and the law we have enunciated above is far from being generally applicable.

The West Indian hurricanes commence for the most part at about 55° W.: some proceeding to the N.N.-westward, preserve their direction till they disappear, passing over the Gulf of Mexico; while others move in a more northerly direction, involving the American Coast, Bermuda, and Azores.

In the Bay of Bengal, the progressive motion is from between E. and S. In the Indian Ocean they appear to form in about 10° S., longitude 105° E., to the westward of Java, whence they proceed W.S.W., and to 28° or 30° S., on to the coast of Africa; frequently, however, in about 70° or 80° longitude, but particularly when approaching the Mauritius, taking a more southerly course, after which they sometimes move E.S.E.† In the China Sea, the Typhoons from between N.E. and S.S.E., and pursue very devious courses. None have been met with between 9° S. and 3° N. In the North Pacific, from Japan to Ladrones or Marianes, they move between N.E. and S.E.

Cyclones whose paths are apparently on the whole directed from the pole to the equator are not unknown. It is evident then, that we are justified only in speaking of the *tendency* of cyclones to move in certain definite directions; even in the North Atlantic where this tendency is the most fully developed, many apparent exceptions occur. Some of the most violent of these storms have been known only in one of the usual branches, and that approximating to a straight line. No rule, therefore, with regard to the track can be laid down which can relieve the seaman from the exercise of his own judgment and due caution.

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* Recurvature may take place in all latitudes from 10° S. to 30° S., but mostly in about 20° S. A line of recurvation upon which these storms mostly change their course, extends from about 85° E. and 12° S., to 55° E. and 27° S. As this line coincides with the tracks of vessels from India and China to Europe, a look-out should be kept.

† The hurricane region, south of Equator, extends more or less over the entire area of the S.E. trades in the Indian Ocean. It is beginning to be ascertained that a well marked region of cyclones extends from the Cape of Good Hope to Australia, about the parallel of 40° S., also the east of Australia is a distinct cyclone region.

One of the most important duties which devolve upon him on being overtaken by a cyclone is to make such observations as shall enable him to determine, at least approximately, the actual track of the storm which he is called to encounter.

Hurricane and Cyclone Seasons.

West Indies and American Coast.

Coasts of Mexico and Lower California in N. Pacific Ocean—*July* to *October* and occasionally in *November*.

In S. Pacific Ocean, between Australian Coast and Low Archipelago—*December* to *March*.

Malabar Coast and Bay of Bengal—*April* and *May*, and *October* to *December*.

South Indian Ocean—*December* to *April*.

China Sea—*July* to *November*.

Coast of Japan—*August, September*, and *October*.

As regards the seasons in which cyclones are chiefly to be met with, it would appear by an analysis of the numbers of these recorded during the several months of the year, that they are to be apprehended most frequently between the summer solstice and the end of the month following the succeeding equinox, or, in other words, from the end of June to October in N. latitude, and in S. latitude from January to April. In the North Atlantic the hurricane season extends from the latter end of June to December, the greatest number occurring in August, and next September.* In tropical regions it may be said in broad terms that the hurricane season begins *near* the summer solstice in both N. and S. latitudes; but the West Indian hurricanes do not, as a rule, occur until *after* the sun has attained his greatest northern declination; while in the Southern Indian Ocean, on the other hand, they may take place a month or more *before* the sun has reached his greatest southern declination. In the Indian Ocean and about Mauritius the chief period of their occurrence is from November to May (both inclusive); they are most frequent in January and March, very few being met with in November and May. In the Bay of Bengal and the Arabian Sea cyclones occur in April and May, and again in October, November, and December, being most frequent at the period of the change of the monsoons—more frequent at the change of the S.W. monsoons (in October and November) than at its commencement (in May and June). In the China Sea the typhoon cyclones occur nearly at the same season as the West Indian hurricanes, from June to September, the worst month being September, the fewest in June. Typhoons have been experienced off the Coast of Japan in July, August, September, and October; in the South Pacific, December and February.

Rate of Progression.

The rate of progression is a most important element of the phenomenon, but it is at the same time that on which least dependence is to be placed. The rates vary not only in different seas, but in the same localities, and at the same seasons. Nor does the extent of the cyclone afford any indication of its rate of travelling, both large and small hurricanes having been known to move with great rapidity, or at moderate or slow rates, apparently without any fixed law. The same storms, too, after remaining almost stationary for hours, or even a day or more, moving at a rate of under two miles an hour, will suddenly start with a continually increasing velocity, while at the same time they expand in area. In general, however, the progressive motion is greatest after its recurvature. According to REDFIELD the hurricane of August, 1855, traversed 7276 English miles in about 12 days, with a mean progressive velocity of 26 miles per hour; but after it had arrived at the banks of Newfoundland, this velocity was increased to about 50 miles per hour. They generally are much diminished in velocity when passing over land, especially when it is much elevated. It seems, too, that they sometimes decrease in area and velocity, but increase fearfully in violence, even when passing over the open ocean. The West Indian and North American hurricanes are stated by Mr. REDFIELD to travel at from 9 to 43 miles an hour, hence 16 or 20 miles may be assumed as the probable *least* rate at which storms may be moving in this part of the world;* those in the Bay of Bengal from 2 to 39 miles an hour, or most usually at the rate of 3 to 15 miles; in the China Sea from 7 to 24 miles. In the Indian Ocean the storm moves more rapidly at first and then steadily at about 200 miles a day, decreasing in about 20° S. and ceasing with the limits of the trades.

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* From a chronological table of the principal hurricanes that have occurred in the West Indies during 150 years, published in *Johnston's Physical Atlas*, it appears that the greatest number occurred in August, so that this month may be regarded as furnishing the most regular but the greatest number of cyclones. M. André Poey, of Havana, has given a chronological table of every hurricane in the North Atlantic of which any record can be traced from 1493 to 1855—a period extending over 363 years—and they amount to 355. And this record assigns 287 to the months of July, August, September, and October, as against 68 for the remaining months of the year, so that the four months just mentioned may be said to constitute the hurricane season of the North Atlantic.

Velocity of Rotation.

It has been already observed that the great characteristic of these storms is that the particles of air in them revolve round the centre with a great rapidity, increasing from the outer circumference until a central space has been reached, at which it is greatest. The velocity of rotation at this point sometimes reaches the value of 125 to 150 miles an hour.

Magnitude of Revolving Storms.

REVOLVING STORMS vary as much in their magnitude as in the rates at which they travel. The diameter of the area, subject to the *force* of the storm at one time is also very variable; but it is undoubtedly small at its origin, increasing in dimensions in its onward progression. They are also supposed to dilate and contract in their progress. Thus the West Indian hurricanes while approaching to or within the Islands do not exceed 100 to 150 miles in diameter, while after reaching the Atlantic Ocean they expand so as often to attain to 600 or 1000 or even 1500* miles in diameter, the wind blowing a severe gale over the whole area, of true hurricane violence towards the centre. In the Bay of Bengal the usual size is from 300 to 350 miles, and in the Arabian Sea they do not exceed 250 to 350. The Southern Indian Ocean cyclones average from 400 to 600 miles in diameter, and the typhoons in the China Sea from 50 to 100 miles.

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* Prof. LOOMIS, in his *Contributions to Meteorology*, gives the rate of storm centres in Europe as 16·7 miles an hour, the average rate over the United States being about two-thirds greater. For the Atlantic Ocean he obtains 18 miles as the average velocity for the entire year. From similar enquiries carried out in the same direction, a writer in the *Nautical Magazine*, September, 1885, considers that 20 to 25 miles an hour is a safer estimate of the rate, at least, in the track of vessels bound to Europe from America.

Diameter of Storm greatly increased after recurving.

While the diameter of the storm, so long as it is within the Tropics, expands very gradually, it increases in a remarkable manner after recurving. It cannot be said with certainty if when they become larger they become more or less violent, but when they contract it is believed they sometimes augment fearfully their violence.

Diameter of Central Space.

The central calm space itself has been found to vary in diameter in different regions and storms from 15 or 20 up to 80 miles; it is said to be largest at first, and to decrease afterwards. The calm has continued at various intervals from a few minutes to eight hours; and short calms alternating with violent gusts have been experienced.

The Axis Line.

The track or line along which the centre of the revolving storm progressively moves is variously termed the storm's track, the storm path, and the axis line. By French writers it is called the trajectory—as indicative of a parabolic track in space (see Figs. 100 and 101).

Axis line divides storms into right and left-hand semicircles.

The axis line or track of the revolving storm divides the storm-field into two parts, and looking in the *direction in which* the storm is moving, the part to the right is the *right-hand* or *starboard semicircle* in the same sense as the right-hand side of a ship is called the *starboard* side, and that to the left the *left-hand* or *port* semicircle.

Anterior and Posterior semi-circles.

Another line, transverse to the axis line and passing through the calm centre, divides the storm-field into four quadrants, each of which has its characteristic predominant wind as seen in Figs. 102 and 103.

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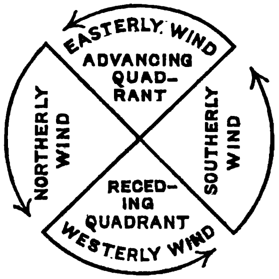
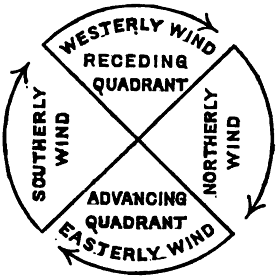
* The extreme breadth assigned, 1500 miles in some cases, requires strong proof. BUCHAN's Chart shows that the proximity of two distinct storms might have led to their reference to one had not the intervening points been observed; and apart from this the observations on which such wide limits are asserted would require to have been made simultaneously.

Fig. 102.



Equator.

Fig. 103.



Those divisions of a cyclone into the axis line, the right and left-hand and front and hinder semicircles, especially when combined with the rotatory or incurving motion, furnish some very important deductions, especially with regard to the hauling of the wind.

Deductions from the Progressive Motion.

If a ship is directly in the path of the storm the wind remains unchanged in direction, but increasing in force until the centre approaches, where a lull or calm prevails; when the centre has passed over her the wind suddenly blows with great fury from the *opposite* quarter (provided it is a circular and not an incurving or spiral storm), and while it continues its force decreases from the calm to the margin (see Fig. 104).

Phenomena during the passage of the axis-line.

In the *right-hand* semicircle the hauling of the wind of a cyclone, in the *northern hemisphere*, is in the same direction as the apparent course of the sun, veering N., N.E., E., S.E., or with the hands of a watch, whether in a rotatory, incurving, or spiral storm.

In N. latitude wind hauls *with* the sun in right-hand semicircle, but hauls *against* the sun in left-hand semicircle.

In the *left-hand* semicircle of a rotatory storm, in the *northern hemisphere*, the wind hauls *against* the sun, veering N., N.W., W., S.W., or against watch hands.

In S. latitude wind hauls *with* the sun in *left-hand* semicircle, but *against* the sun in *right-hand* semicircle.

In the *Southern Hemisphere* it is the *left-hand* semicircle in which the hauling of the wind is in the same direction as the apparent course of the sun, veering S., S.E., E., N.E.

But it is the *right-hand* semicircle when in S. latitude, in which the wind hauls *against the sun*, veering S., S.W., W., N.W., or with watch hands: hence

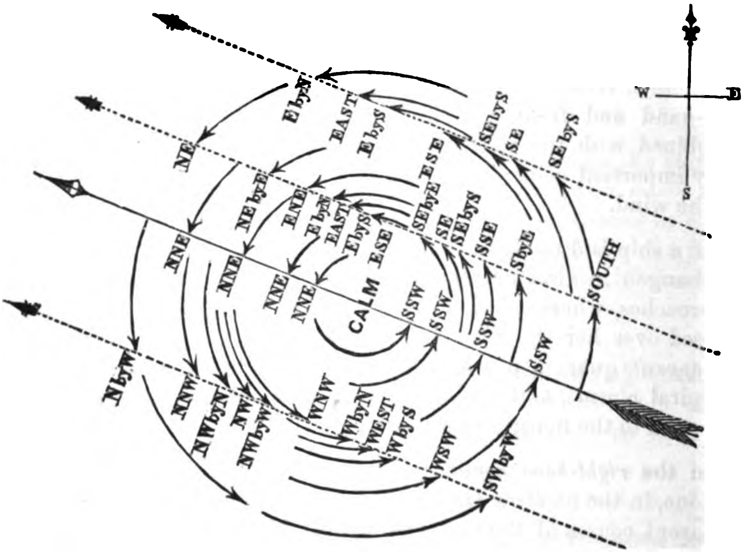
Wind veers to *right* in right-hand semicircle, but veers to *left* in left-hand semicircle.

To know whether the ship is in the right or left-hand semicircle of the storm or of the advancing centre, note the veering of the wind, and if it veers to the **right,** the ship is in the **right-hand semicircle,** but if it veers to the **left,** the ship is in the **left-hand semicircle.**

In using the above rule it is essential that the ship's position be as nearly as possible stationary; for if a ship continues her course the wind may shift in a direction exactly opposite to that which would have been observed had the vessel been stationary, and an erroneons conclusion as to her position in the storm will be drawn. The advisability of heaving-to on the first approach of a hurricane cannot therefore be too strongly recommended.

The following figure may be of use to assist the reader to gain a precise idea of the nature of these storms. It is supposed to represent a revolving storm in N. latitude, the revolution being in the direction of the curved arrows, while it travels forward in the direction of the large straight arrow, or from E.S.E. to W.N.W.; and if we suppose it to pass over three different ships, situated at different distances from the central track, the effects on them will be the same as if the storm had no progressive

Fig. 104.



motion, and they travelled through it from W.N.W. to E.S.E., along the three dotted lines, parallel to the large arrow, but in the opposite direction thereto. By following either of these lines it will be perceived that the wind will blow in succession from the various points marked on each dotted line. For instance, the storm, as experienced by the northernmost ship, will begin with the wind at E. by N., and veer round through six points, to S.E. by S. at the end of the storm. The southernmost ship being nearer the central track of the storm will have the wind veering through ten points, beginning at N. by W. and ending at S.W. by W.; while the middle ship, being still nearer the storm's centre, will experience the wind first at N.E., veering through twelve points, until it finishes at S. If we observe the distances between the several arrow-heads on either of these lines, especially the last, it will be seen that they are more numerous towards the middle of the line, showing that the veering of the wind is most gradual on the margin of the storm, and most rapid the nearer the centre. But the farther a vessel is from the axis line, the less perceptible will this difference be; for example, on the northmost line in the figure, the arrow-heads are more nearly equidistant, showing that the change of wind experienced is more equable, or nearly as gradual at the middle of the duration of the storm as at its beginning or end. It will also be observed, that the nearer the ship approaches the storm's centre the greater will be the number of points through which the wind veers; but this number can never exceed fifteen points, for when a ship is on the axis line there is no change of wind, but a constantly increasing gale, until the centre has passed, when after a short lull or calm, the wind springs up with great fury from the opposite quarter.

The Rotatory motion increases the effect of progressive motion in right-hand semicircle, but decreases it in left-hand semicircle.

The revolving motion of a cyclone increases the effect of the progressive motion in that semicircle which is on the right-hand of the axis line, the two motions being approximately in the same direction; but it diminishes it in that semicircle which is on the *left* of the same line, the two motions in this case being approximately opposed to each other.

NOTE.—For example, if the velocity of revolution be 80 miles an hour, and that of progression be 20 miles an hour, the velocity of its quickest moving part will be equal to their sum, or 100 miles an hour, while the opposite side will only move at the rate of their difference, or 60 miles an hour, so that the violence of the gale will be greater on the one side than the other, in the ratio of 5 to 3.

On this account the right-hand semicircle, in which the wind increases in violence, has been called the *dangerous* side; while the *left-hand* semicircle, in which the winds are of diminished

Fig. 105.

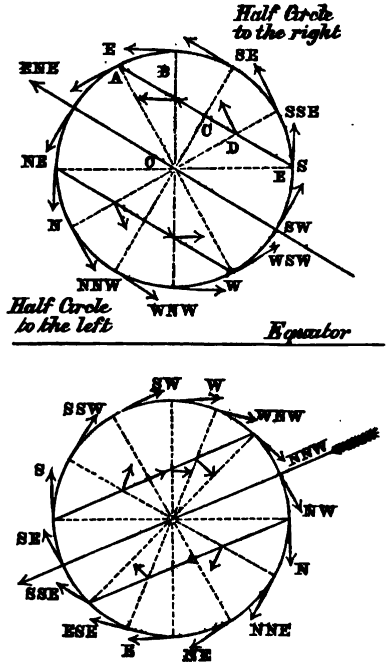
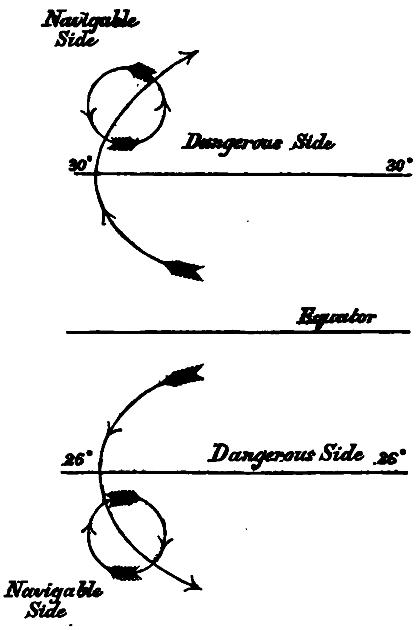


Fig. 106.



violence, has been called the *tractable* or *navigable* side.* A glance at the long curved arrows (Fig. 105), one north and the other south of the equator, which represents for each hemisphere the storm's track, shows that the *dangerous* side always lies between the two sides, or *eastward* of the parabolic track, while the *navigable* side lies *outside*, or to the westward; or in relation to *right* and *left* of the track the positions are:—

In N. latitude the *dangerous* semicircle is to the *right*, and the *navigable* to the *left* of the track.

In S. latitude the position of the two sides are reversed, the *dangerous* side lying to the *left* and the navigable side to the *right* of the track.

Each storm path in the northern hemisphere is directed, generally speaking, towards one of the following points—the N.W., N., or N.E., while in the South hemisphere, the points to which the hurricane may advance are S.W., S., or S.E. A cyclone advancing towards any one of these points exhibits certain changes of the wind in the right and left-hand semicircles.

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* French writers, speaking of the two sides of the storm-field, have applied the term "dangerous" (*dangereux*) to the semicircle in which the rotatory and progressive motions of winds are approximately in the same direction; and the term "tractable," perhaps better "navigable," to the semicircle in which the two motions are approximately opposed to each other.

The winds for each semicircle are as follows:—

IN THE NORTHERN HEMISPHERE.

Storm moving towards N.W.—

In *dangerous* semicircle, winds from N.E. to S.W. round by E. and S.

In *navigable* semicircle, winds from N.E. to S.W. round by N. and W.

Storm recurving to northward—

In *dangerous* semicircle, winds from E. to W. round by S.

In the *navigable* semicircle, winds from E. to W. round by N.

Storm moving towards N.E.—

In *dangerous* semicircle, winds from S.E. to N.W. round by S. and W.

In *navigable* semicircle, winds from S.E. to N.W. round by E. and N.

IN THE SOUTHERN HEMISPHERE.

Storm moving towards S.W.—

In *dangerous* semicircle, winds from S.E. to N.W. round by E. and N.

In *navigable* semicircle, winds from S.E. to N.W. round by S. and W.

Storm recurving to southward—

In *dangerous* semicircle, winds from E. to W. round by N.

In *navigable* semicircle, winds from E. to W. round by S.

Storm moving towards S.E.—

In *dangerous* semicircle, winds from N.E. to S.W. round by N. and W.

In *navigable* semicircle, winds from N.E. to S.W. round by E. and S.

The following arrangement of winds may be found useful in determining the progression of a Revolving Storm.

NORTH LATITUDE.

Wind	E.,	veering to the	*right*,	storm moving	N.W.
„	E.	„	*left*,	„	N.E.
„	S.	„	*right*,	„	N.E.
„	N.	„	*left*,	„	N.W.

SOUTH LATITUDE.

Wind	E.,	veering to the	*left*,	storm moving	S.W.
„	E.	„	*right*,	„	S.E.
„	S.	„	*right*,	„	S.W.
„	N.	„	*left*,	„	S.E.

It is, moreover, easy to see that in the northern hemisphere, when running before the wind, in the right-hand semicircle the ship approaches rapidly to the centre, and even when lying on the starboard tack, which is the only possible manœuvre, she still drifts in that direction.

In the left-hand semicircle, on the contrary, even if the violence of the sea renders it imperative to place the ship on the port tack, she will move away from the centre, and by running before the wind she may rapidly get away from it.

If instead of dividing the storm as above by a line parallel to its progress into the advancing or quicker side, and the receding or slower side (the semicircle on either side of the axis line being characterised by different haulings of the wind) a line be drawn at right-angles to the central track and intersecting it at the centre, thus dividing it into the preceding and succeeding halves—each half being characterised by increasing and decreasing forces of wind—it will be seen that a vessel in the front half of the storm runs far greater danger of being exposed to all its fury and for a longer time, than one which enters its hinder half. If a ship be put before the wind in the *advancing* quadrant of the *left-hand* semicircle in the northern hemisphere, as in Fig. 107, she will *recede from the axis line*, and consequently be removed from the danger of the centre bearing down upon her, but if she be put before the wind in the *advancing* quadrant of the *right-hand* semicircle, she must inevitably approach nearer and nearer the axis line, and may, under such circumstances, meet the centre, this quadrant has consequently received the name of the *most dangerous quadrant* of the cyclone. In either of the remaining quadrants a ship may very readily extricate herself from the influence of the hurricane, provided she has plenty of sea-room.

Fig. 107.
N. Latitude.

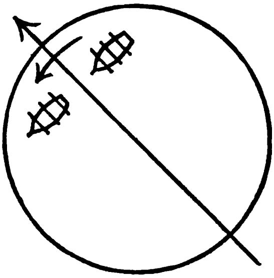
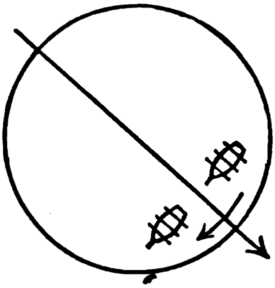


Fig. 108.
S. Latitude.



In the southern hemisphere a reversal of the phenomenon occasions a reversal of the most dangerous quadrants, so far as the right and left-hand semicircles are concerned. In the southern hemisphere it is the *advancing* quadrant of the *left-hand* *semicircle* that is the most dangerous quadrant (as shown in Fig. 108), where the vessel put before the wind in the *right-hand* semicircle recedes from the axis-line, but the vessel in the *left-hand semicircle* is approaching it. The most dangerous quadrant, therefore, is that which belongs both to the front and to the advancing or quicker semicircle. Hence the following important general rule:—

That in the NORTHERN *hemisphere the most dangerous quadrant of a cyclone is the* ADVANCING *quadrant of the* RIGHT-HAND SEMICIRCLE; *but in the* SOUTHERN *hemisphere it is the* ADVANCING *quadrant of the* LEFT-HAND SEMICIRCLE.

The remarks hitherto have related to the phenomena resulting from the two-fold motion of a hurricane. We may now not inappropriately introduce a very important deduction of a highly practical nature. It is the side on which a vessel will receive the wind in a revolving storm* according as she is sailing towards the *centre* or *margin*. When a ship in N. latitude meets a revolving storm, when sailing *from* the centre to the margin, she will receive the wind on her *starboard* side, but if her head is directed towards its *centre*, she will receive the wind on her *port* side: and when a ship in S. latitude meets a revolving storm she receives the wind on her *port* side when *sailing out of*, but when *sailing towards*, the centre she will receive the wind on her *starboard* side (see Figs. 109 and 110).

Fig. 109.

Northern Hemisphere.

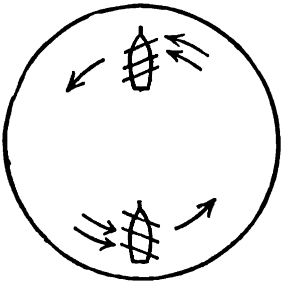
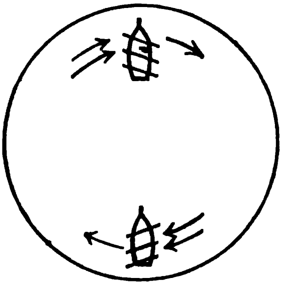


Fig. 110.

Southern Hemisphere.



These facts readily indicate the means adopted, either to retire to or beyond the margin of the storm or to draw from the centre when lying-to. The rules suggested are,

The STARBOARD *tack in* N. *latitude,*
And the PORT *tack in* S. *latitude,*
Will always take the ship away from the focus.

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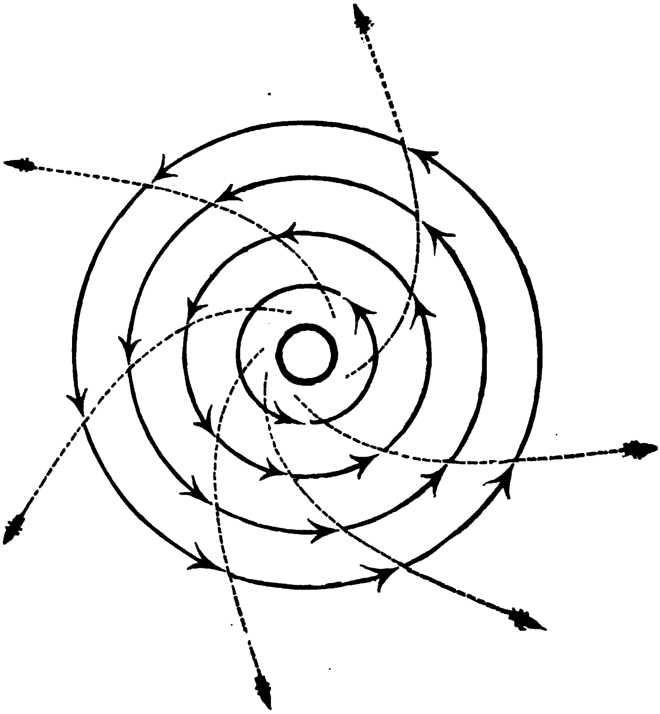
* The same rules apply equally to an incurving or spiral storm.

The following figure is intended to show what would be the track of a ship in N. latitude when steered so as to keep the wind on the starboard quarter. The reverse of this figure (which may be obtained by holding the leaf up to light with its back turned to the eye) will show what would be the track of a ship in S. latitude when steered so as to keep the wind on the port quarter. These figures represent the tracks of ships in revolving storms to be supposed stationary. In gales having progressive movement such tracks would be modified.

Fig. 111.



When it is considered desirable that the ship should be hove-to that tack should be selected on which the wind draws aft, because from the extreme violence of the wind, there is danger if it should head the ship of her getting sternway; therefore

When a vessel is in the RIGHT-HAND SEMICIRCLE heave-to on the STARBOARD TACK, but

When in the LEFT-HAND SEMICIRCLE heave-to on the PORT TACK.

In this way the ship will COME UP as the *wind shifts*, instead of falling off from it.

Running is never recommended except as a necessity.

Ship on the direct path of centre.—If, with the ship hove-to the wind continues steady in the same direction, increasng in violence with a rapidly falling barometer, it may be presumed that the ship lies on the direct path of the storm's centre, and it will be necessary to run before the wind.

If the vessel be unable, from want of sea room, to run her position becomes one of great danger, and every precaution should be taken to prepare for the passage of the centre over the ship; for the steady wind will be succeeded by a short interval of calm, to be followed by a sudden and most violent burst of wind from the opposite point of the compass from that from which the wind has been blowing. After the calm the barometer will commence slowly to rise.

It has sometimes been advised that a vessel should always scud before a cyclone. Lieut.-Col. Reid shows, that although there is one quadrant of the storm in which, by scudding, a ship will be carried beyond its influence; yet, in the opposite quarter, scudding will be especially dangerous, as tending to carry the vessel across before the progress of the centre of the storm. This will obviously be the case in the front or forward half of the left-hand semicircle of a storm in N. latitude, or in the forward half of the left hand semicircle of one of the storms of the Indian Ocean.

When a ship can run she will of course make for the nearest edge or limit of a revolving storm, and cases have occurred in which, under favourable circumstances, a ship has even made a fair wind of a cyclone. Running, however, is attended with risk of losing the masts and upsetting, or broaching-to, as it is very difficult to take in sail in a violent storm. And again, in consequence of the variable path of the storm in higher latitudes, it is only in low latitudes that such a course could be taken.

Heaving-to, as has already been stated, will always be dangerous when in front of the cyclone and near the line of progression of the storm, and having reason to believe the ship is in that position, avoid heaving-to under the following circumstances, unless compelled to do so.

When in the Northern hemisphere.
  Storm moving to N.W., winds between N.N.E. and E.N.E.
  Storm recurving, winds between E.N.E. and E.S.E.
  Storm moving North-easterly, winds between E.S.E. and S.S.E.

When in the southern hemisphere.
  Storm moving South-westerly, winds between S.S.E. and E.S.E.
  Storm recurving, winds between E.S.E. and E.N.E.
  Storm moving South-easterly, winds between E.N.E. and N.N.E.

The first of two figures here inserted is intended to represent one of the West Indian hurricanes, moving towards the N.W. by N., in the direction of the spear drawn obliquely. It may be ascertained what part of a revolving storm a ship is falling into by observing, as already stated, how the wind begins to veer. Thus, in the first figure, the ship which falls into the right-hand semicircle, would receive the wind at first about E. by N.; but it would soon veer to East as the storm passed onward and supposing her lying-to; but if a ship fall into the left semicircle, it would at first receive the wind at N.E.; but with this latter ship, instead of veering towards East, it would veer towards North.

The explanation of the rule will best be made out by attentively inspecting the two figures. *In both, the black ships are on their proper tacks*, i.e., *the tacks on which they will come up to the wind;* the white ships on the tacks on which they will fall off.

Fig. 113 is intended to represent one of those hurricanes in S. latitude, which pass near Mauritius, proceeding to the S.W.-ward. The storm is supposed to be moving S.W. by S. in the direction of the spear-head. It will be seen that the black ships are always coming-up, and the white ships always breaking off; and that they are on opposite tacks on opposite sides of the circles.

From this rule it follows that if two ships be hove-to within the compass of the same revolving storm and on the same tack, and the one ship falls off, the centre of such revolving storm will be passing between them. By this means we may judge approximately of the track a storm may be following, even in the case of single ships.

In some cases, however, should the ship forge ahead, she will draw towards the track of the centre of the storm. If we look at the black ships, in the *left* hand semicircle of the figure for N. latitude, and in the *right* hand semicircle of the figure for S. latitude, it will be seen that these black ships point with their heads towards the centre of the storm. If they forge ahead they will draw towards the track of the centre. As a general rule, therefore, it may be preferable to heave-to on the starboard tack in N. latitude, and on the port tack in S. latitude; the ship will, under these circumstances, draw from the storm's centre.

When bound westward, in either N. or S. latitude, a vessel will meet with favourable winds from the eastward in the *advancing* semicircle.

In N. or S. latitudes, vessels bound to the eastward will meet with favourable winds in the *receding* semicircle.

The application of these rules would be comparatively easy if the course of the storm were nearly straight; but they become difficult when the storm is sweeping round the most curved part

Fig. 112.

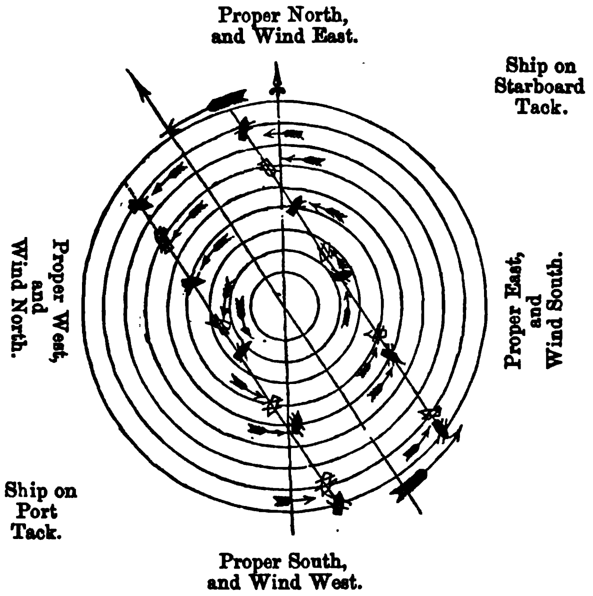
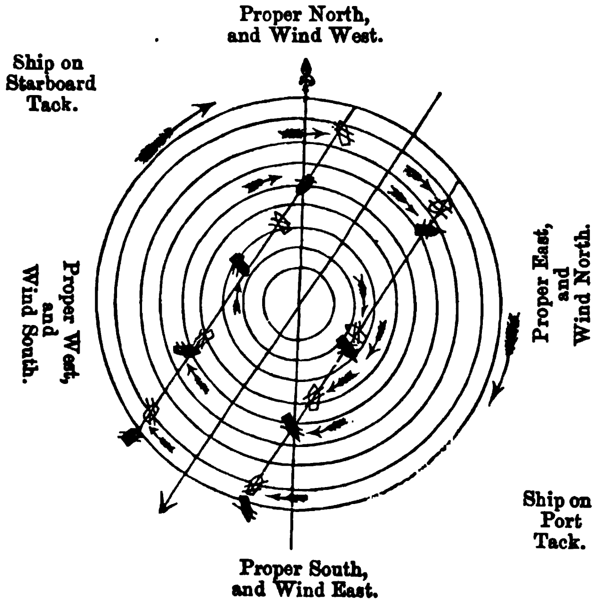

Proper North, and Wind East.
Ship on Starboard Tack.
Proper West, and Wind North.
Proper East, and Wind South.
Ship on Port Tack.
Proper South, and Wind West.

Fig. 113.


Proper North, and Wind West.
Ship on Starboard Tack.
Proper West, and Wind South.
Proper East, and Wind North.
Ship on Port Tack.
Proper South, and Wind East.

of its track, or recurves usually, as before stated, at about latitude 25° or 30°, where the ship may often be twice involved in the vertex. It is at this particular part of their track that cyclones have produced the most fatal effects at sea; and hence it is that the most dreaded part of the Atlantic is near the Bahamas and Florida; and that of the Indian Ocean, to the South of Mauritius and Bourbon.

When bound westward in a revolving gale between the latitudes of 10° and 40° N., it is necessary to keep a good look-out for the *bend* of the storm; the more so if S.E., E., or N.E. winds be met with. If bad weather is found rapidly to increase and the easterly winds *hang*, the storm is *recurving*.

The entire storm paths of the Western Atlantic are characterised by certain winds that are *most dangerous* to vessels falling in with them, according to the locality, as follows:—

1. **Before recurving**—off the West India Islands—the most dangerous hurricane winds are those between E.N.E. and N.E.

2. **About the period of recurving,** vessels off the Bahamas and the Coast of Florida find E., E.S.E., and S.E. winds most dangerous.

3. **After recurving,** vessels off the coasts of the United States find E.S.E. to S.S.E. and S. winds most dangerous.

The general sweep of dangerous winds in the North Atlantic may be specified:—

N.E., E.N.E., E., E.S.E., S.E., S.S.E., and S.

Between the latitudes of 10° and 30° S., when bound westward and in a revolving storm, it is necessary to keep a vigilant look-out for the *bend;* the more especially if N.E., E., or S.E. winds be met with. If from stress of weather the vessel being hove-to, and an easterly wind *hangs*, the storm is *recurving*.

In the Southern Indian Ocean, if the cyclone be moving towards the S.W., the most dangerous winds are those between S. and E., but when moving towards the S.E., winds between the E. and N. are the most dangerous.

So that in both hemispheres winds inclining to westerly are comparatively safe, while such as have easting in them require caution, skill, and judgment in manœuvring the ship under whatever circumstances they are encountered—whether by running into them, or being overtaken by a hurricane.

In N. latitude, if a ship bound *westward* meet with the S. or S.W. winds of a hurricane, she will at first sail into the heart of the storm, and then be "headed off" her course. By heaving-to on the *starboard* tack, "waiting on" the storm while it gets *northing*, and, if needs be, standing to the eastward, the position of the vessel will mostly be improved, and the wake of the storm may be crossed with safety.

If, in S. latitude, and bound *westward,* the N. or N.W. winds of a revolving gale be met with, heave-to on the *port* tack, "wait on" the storm while it gains *southing,* and stand to the *eastward* if necessary.

INDICATIONS.—As waves may be propagated with great rapidity, a swell more or less confused has been noticed as the indication of an approaching or passing hurricane.

A noise in the air heralds as it were the approaching storm, and an unusual glare or colour in the light, commonly of a red hue, has been observed.

All accounts describe a hurricane as attended by a remarkably dense lofty wall or bank of cloud, of a dark or leaden appearance. As the vessel approaches the storm the bank of cloud appears to advance and draw closely down upon the ship. Scud seen flying in different directions is, of course, a sign of nearer approach.

One of the most important indications in the tropics is afforded by the barometer, because the height of the barometer is, in those regions, very nearly constant.

The barometer generally falls slowly, but steadily, for some time previous to a hurricane.* If a diameter of the storm be drawn transverse to the axis line dividing the starboard and port semicircles into two equal quadrants, it will exhibit those portions of the storm in which the barometer will fall and rise. Whilst the first half of a storm is passing a ship the mercury will fall, and whilst the succeeding half is passing the barometer will rise. The transverse diameter will also be characterised by a barometer which is proportionably lower as the focus draws near.

At or near the focus the depression is greater. The extreme fall recorded is from 29·0 to 26·3, or 2·7, and it is supposed to have fallen still more.

In most cases of manœuvring it is desirable to keep just within the verge of the storm; and here the barometer is of signal benefit, since by keeping it as high as possible without losing the cyclone winds the vessel is kept just within the margin of the storm.

It has also been observed, that previously to a hurricane the barometer has stood higher than usual. Colonel REID accounts for this by supposing that the advancing whirlwind interferes with the usual progress of the winds, and tends to heap up the air in its path, thereby increasing its pressure or weight.

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* The fall usually begins about 72 hours before the storm, and indicates its approach when it is as much as 800 or 900 miles off at least.

Lieut.-Col. Reid considers that the indications of a progressive revolving storm are a descending barometer, with a regularly veering wind, or with the shifting suddenly to the opposite point, as also an increase of warmth and moisture; while on the other hand he considers that a high and stationary barometer attends a wind constant to the same point.

General directions as to manœuvres.—The following general directions as to the manœuvres to be made in a cyclone are drawn from the most recent writers.

When in the region and in the season of revolving storms, the seaman should be on the watch for premonitory signs. *Constantly and carefully observe and record the barometer.*

When there are indications of a cyclone being near heave-to, and carefully observe and record the changes of the barometer and wind, so as to find the bearing of the centre, and ascertain by the shifting of the wind in which semicircle the vessel is situated (see pages 395 and 396). Much will often depend upon heaving-to in time.

When, after careful observation, there is reason to believe that the centre of a cyclone is approaching, the following rules should be followed in determining whether to remain hove-to or not, and the tack on which to remain hove-to:—

N. Hemisphere.—If in the right-hand semicircle, heave-to on the starboard tack. If in the left-hand semicircle, run, keeping the wind, if possible, on the starboard quarter; and when the barometer rises, if necessary, to keep the ship from going too far from her proper course, heave-to on the port tack (see page 402).

S. Hemisphere.—If in the right-hand semicircle, run, keeping the wind, if possible, on the port quarter; and when the barometer rises, if necessary, to keep the ship from going too far from her proper course, heave-to on the starboard tack. If in the left-hand semicircle, heave-to on the port tack (see Fig. 111, page 402).

Both Hemispheres.—When the ship lies in the direct line of advance of the storm—which position is the most dangerous of all—run. And in all cases act so as to increase as soon as possible the distance from the centre; bearing in mind that the whole storm-field is advancing.

In receding from the centre of a cyclone the barometer will rise, and the wind and sea subside.

QUESTIONS RELATING TO CYCLONES OR REVOLVING STORMS COMMON IN TROPICAL SEAS.

An applicant for a Master's Certificate for Foreign-going Vessels must answer in writing, on paper supplied to him by the Examiner, the following Questions, numbering the answers to correspond with the Questions.

Question—

1. The direction of wind in a Cyclone being*——————, state the probable bearing of its centre from the ship in the *——————Hemisphere.
2. And suppose that the wind during the passage of the same Cyclone were found to change toward the*——————, what would be the ship's position with reference to the line of progression of the centre of the Cyclone, and what action would you take?
3. Under what conditions would the change in the direction of the wind in the Cyclone be the reverse of the above?
4. What are the usual indications of a ship being on the line of progression of the centre of a Cyclone?
5. What are the usual indications that a ship is (*a*) approaching the centre of a Cyclone; (*b*) receding from it?
6. Describe the track usually taken by cyclones in the†——————, and state the seasons of the year in which they most frequently occur in that region.

The questions set to Candidates are framed with a view to elicit the fact of their possessing sufficient knowledge of the subject to avoid any gross mistake in the management of ships in a cyclone. All answers may be based on the purely circular theory, that is, allowing eight points for finding the bearing of the centre (see pages 388 and 389), and on the rules deduced from this for escaping the centre (see page 402). The Candidate having answered No. 1 as just directed, must read No. 2 attentively. (*Never attempt to answer any question without having first carefully read it through from the beginning.*) Next look at No. 6 and note what locality is mentioned. Now draw a small circle, if ever so rude, on the margin of your paper, abreast of the space allotted for your answer to No. 2; put little arrow barbs on the circle to show which way the WIND is revolving, and a long straight arrow through the centre to denote the direction the storm is travelling—the arrows being supposed to fly *with* the wind or storm not *against* it. The circle will show where the ship was, first, when she had the wind as given in No. 1, and next, her place when it has changed as in No. 2 (see Figs. 98 and 99, page 387).

Having ascertained where the ship is, proceed to answer No. 2.

Note particularly if the ship is in the dangerous quadrant (see pages 398 and 401); if so, do not state in your answer that you would run (see page 401). In answering this question a course should, if possible, be made at *right-angles* to the line of progression, keeping the wind on the proper side for the latitude. Starboard side in N. lat., port side in S. lat. (pages 401 and 407); and note the circle you have drawn to see if the direction of the wind allows it.

To be practical the winds and their changes given in Nos. 1 and 2 are, or ought to be, dependent upon the locality named in No. 6. From the outset of the study frequently consult page 392, until you get a fair idea of how cyclones travel in all the various latitudes.

Nos. 3, 4 and 5 being fixed questions the answers given in the Examples, Paper I, will suffice.

With respect to No. 6, if only an Ocean be named, it may be doubtful what part of that Ocean is meant when the diagram to No. 2 is to be sketched; as, for example, the Indian Ocean. Here storms may be proceeding W.S.W., S.W., S., S.S.E. or E.S.E. (see page 391). In such a case the proper way is to state all these courses in the answer to Question 6, and the *changes of wind* in Questions 1 and 2 will indicate the track to assume for Question 2.

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* These spaces to be filled in by the Examiners, and frequently varied.

† The Examiners to fill in whether North Atlantic, Bay of Bengal, China Seas, Indian Ocean, &c., &c.

PAPER I.

1. The direction of the wind in a cyclone being South* state the probable bearing of its centre from the ship in the Northern Hemisphere.

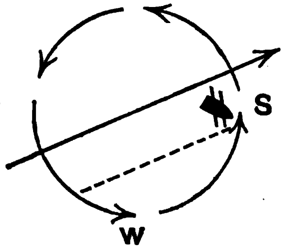
Answer.—In the Northern Hemisphere the centre bears 8 points to the *right* of the direction of the wind; therefore, the centre will bear West.

2. And suppose that the wind during the passage of the same cyclone was found to change towards the S.W.,* what would be the ship's position with reference to the line of progression of the centre of the cyclone, and what action would you take?

Answer.—The wind veering to the right the ship would be in the right-hand semicircle. I would sail her with the wind on the starboard side until in a safe position, and then, if need be, heave-to on the starboard tack. Should the barometer again fall, sail her, as before, further out.

Remarks.—Ship in northern part of North Atlantic Ocean (see Question 6). If the wind blow from the South quarter, that is, from any point between S.E. and S.W. on the southern horizon, increasing in force, and at the same time hauling *with the sun*, or from South to S.W., the ship is in the *right-hand semicircle* (see pages 395 and 396), and the centre bears *Eight* points from her, reckoned *with the sun*, from the direction of the wind (see top of page 389), the storm itself moving N.E.

Fig. 114.



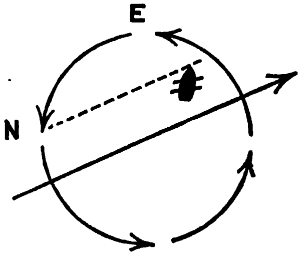
Example in Illustration.—A ship in lat. 45° N., long. 48° W., with an increasing wind from the South, and falling barometer. The wind hauls to the S.W., that is, *with the sun*, the ship is, therefore, in the *right-hand semicircle* of the storm, the centre bearing at first West and then N.W., or *Eight* points from the wind, reckoned *with the sun*, and the storm is moving towards the N.E. (Fig. 114.)

3. Under what condition would the change in the direction of the wind in the cyclone be the reverse of the above?

Answer.—The change in the direction of the wind would be the reverse of that given in Question 2 if the ship were on the other side of the line of progression of the cyclone. If the ship was on the same side and she (heading in the direction in which the centre of the cyclone was moving) overtaking or going faster than the centre progressed, the wind would also veer the other way.

Remarks.—Ship in northern part of North Atlantic Ocean (as before). If the wind blows from the East quarter, that is, from any point between S.E. and N.E., on the eastern horizon, increasing in force, and at the same time hauling *against the sun*, or from E. to N.E., the ship is in the *left-hand semicircle* (see pages 395 and 396), and the centre bears *Eight* points from her, reckoned *with the sun*, from the direction of the wind (see top of page 389), the storm itself moving towards the N.E.

Fig. 115.



Example in Illustration.—Another ship in lat. 46° N., long. 58° W., experiences a wind from East, which hauls to N.E., or *against the sun*, with a falling barometer. This ship is in the *left-hand semicircle* of the same storm, the centre bearing South and S.E., *Eight* points from the wind, also reckoned *with the sun*, and the storm is moving towards the N.E. (see Fig. 115 annexed). Run, keeping the wind, if possible, on the starboard quarter; and when the barometer rises, if necessary, to keep the ship from going too far from the proper course, heave-to on the port tack.

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* The direction of the wind is to be filled in by the Examiner and frequently varied,

4. **What are the usual indications of a ship being on the line of progression of the centre of a cyclone?**

Answer.—There is little or no change in the direction of the wind, which, however, is increasing rapidly in force, with a continually falling barometer, a dangerous sea, and ugly bunts of cloud in the direction of the storm-field. (See Fig. 104, pages 396 and 397.)

5. **What are the usual indications that a ship is (*a*) approaching the centre of a cyclone? (*b*) receding from it?**

Answer.—(*a*) *Approaching.*—The barometer, already low, falls rapidly, more threatening appearance of the weather, dense cloud bank, gale rapidly increasing in violence, with terrific squalls quickly following each other. Wind veering more rapidly (except ship on the line of progression), the sea becoming cross and dangerous. (*b*) *Receding.*—The barometer rising, wind subsiding, sky clearing, but the sea still confused and dangerous. (Fig. 104).

6. **Describe the track usually taken by cyclones in the North Atlantic, and state the seasons of the year in which they most frequently occur in that region.**

Answer.—They originate a few degrees north of the equator, about 10° or 12° N. latitude, and from 40° to 60° W. longitude; then travel W.N.W. to about the West India Islands, where they recurve to the North, and then to the N.E. and E.N.E., gradually increasing in diameter until the become expended and break up.

The North Atlantic Cyclones may be expected from July to beginning of November.

The diagrams (Figs. 114 to 123, on pages 410 to 415) are intended to show the positions of vessels in storms in such a way as to indicate the passages of the storms *over them*, in the direction of the *dotted lines*. It will be remarked that each vessel is on the proper tack *to bring her head from the centre*. In the *Northern Hemisphere*, a vessel on the *starboard* tack will sail out of a Revolving Storm; in the *Southern Hemisphere*, a vessel on the *port* tack will do the same.

PAPER II.

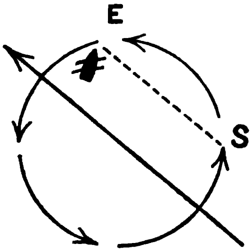
1. **The direction of the wind in a cyclone being East, state the probable bearing of its centre from the ship in the Northern Hemisphere.**

Answer.—About South.

2. **And suppose that the wind during the passage of the same cyclone was found to change toward the S.E., what would be the ship's position with reference to the line of progression of the centre of the cyclone, and what action would you take?**

Answer.—Wind veering to the right; therefore the ship is in the right-hand (or starboard) semicircle (see lower part of page 399). Either shape a course away from the centre of the storm, or heave-to on the starboard tack.

Fig 116.

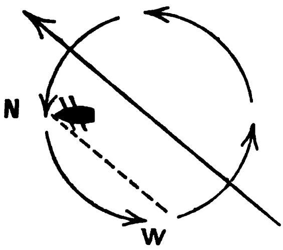


Example in Illustration.—Suppose a ship in lat. 24° N., long. 65° W., with an increasing wind from East, and falling barometer; the wind hauls, as above, to S.E., that is, *with the sun;* the ship, therefore, is in the *right-hand* semicircle of the storm, the centre bearing first South (see Question 1 above) and then S.W., or *eight* points from the wind, reckoned *with the sun*, and the storm is moving towards the N.W. (see Fig. 116).

3. **Under what conditions would the change in the direction of the wind in the cyclone be the reverse of the above?**

Answer.—If the vessel were in the opposite semicircle; or if on the same side as before, and the vessel be moving faster than the storm and in the same direction, the shift may be in the opposite direction to what has been stated in answer to Question 2.

Fig. 117.



Example in Illustration.—A ship, in latitude 22° N., longitude 69° W., with an *increasing* wind from North, and falling barometer. The wind hauls to N.W., that is, *against the sun;* the ship is, therefore, in the front quadrant of *left-hand* semicircle of the storm, the centre bearing at first East then N.E., or *eight* points from the wind, reckoned *with the sun*, and the storm is moving towards N.W. Run, keeping the wind, if possible, on the starboard quarter; and when the barometer rises, if necessary, to keep the ship from going too far from her proper course, heave-to on the port tack (see page 408).

4. What are the usual indications of a ship being on the line of progression of the centre of a cyclone?

Answer.—See answer to the same question in Paper I.

5. What are the usual indications that a ship is (*a*) approaching the centre of a cyclone? (*b*) receding from it?

Answer.—See answer to the same question in Paper I.

6. Describe the track usually taken by cyclones in the West Indies, and state the season of the year in which they most frequently occur in that region.

Answer.—In this region storms mostly travel towards the W.N.W. or N.W. The season is from July to October, August and September being the worst months.

PAPER III.

1. The direction of the wind in a cyclone being East, state the probable bearing of its centre from the ship in the Southern Hemisphere.

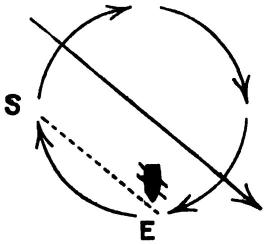
Answer.—The centre bears North.

2. And suppose the wind during the passage of the same cyclone was found to change towards the S.E., what would be the ship's position with reference to the line of progression of the centre of the cyclone, and what action would you take?

Answer.—Wind veering to the right; therefore, the ship is in the *right-hand* semicircle. I would sail her with the wind on the port side until in a safe position, and then, if need be, heave-to on the starboard tack. Should the barometer again fall, sail her, as before, further out (see page 408).

Remarks.—The ship is in the south part of the Southern Indian Ocean, and if the wind blow from the East quarter, that is, from any point between N.E. and S.E. on the eastern horizon, increasing in force, and at the same time hauling *against the sun*, or from East to S.E., the ship is in the *right-hand semicircle* (see pages 395 and 396), and the centre bears *Eight* points from her, reckoned *with the sun*, from the direction of the wind (see top of page 389), the storm itself moving towards the S.W.

Fig. 118.



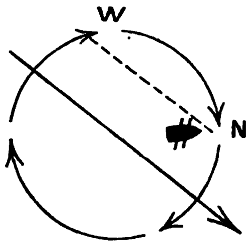
Example in Illustration.—A ship in lat. 35° S., long. 65° E., with an increasing wind from East and falling barometer. The wind hauls to S.E., that is, *against the sun;* the ship is, therefore, in the *right-hand semicircle* of the storm; the centre being first North and then N.E., or *eight* points from the wind, reckoned *with the sun*, and the storm is moving towards the S.E. By Question 6 the locality is the Indian Ocean. It will be at once apparent that the ship's position is in the southern verge of the storm, but not in the dangerous quadrant.

3. Under what condition would the change in the direction of the wind in the cyclone be the reverse of the above?

Answer.—If the ship were on the other side of the line of progression, or if overtaking or going faster than the storm on the same side as before.

Remarks.—If the wind blow from the North quarter, that is, from any point between N.E. and N.W. on the northern horizon, increasing in force, and at the same time hauling *with* the sun, or from North to N.W., the ship is in the *left-hand semicircle*, and the centre bears *eight* points from her, reckoned *with the sun*, from the direction of the wind (see top of page 389), the storm itself moving towards S.E.

Fig. 119.



Example in Illustration.—Ship in lat. 32° S., long. 68° E., (the locality (Question 6) being the Indian Ocean), with an increasing wind from North and falling barometer. The wind hauls to the N.W., that is, *with the sun;* the ship, therefore, is in the *left-hand semicircle* of the same storm; the centre bearing at first West and then S.W., or *eight* points from the wind, reckoned *with the sun,* and the storm is moving towards the S.E. The position of the ship is here on the southern verge of the storm, and in the "dangerous quadrant." To run in such case she must be headed away to the N.E.

4. What are the usual indications of a ship being on the line of progression of the centre of a cyclone?

Answer.—See answer to same question in Paper I.

5. What are the usual indications that a ship is (*a*) approaching the centre of a cyclone? (*b*) receding from it?

Answer.—See answer to same question in Paper I.

6. Describe the track usually taken by cyclones in the Indian Ocean, and state the seasons of the year in which they most frequently occur in that region.

Answer.—They appear to form in about lat. 10° S., long. 105° E., to the westward of Java, whence they proceed W.S.W. and S.W. to 28° or 30° S., on the coast of Africa; frequently, however, in about 70° or 80° long., but particularly when approaching Mauritius, taking a more southerly course, after which they sometimes move E.S.E., gradually increasing in diameter, but somewhat less violent as they progress, until they become expended and break up.

The months of January, February, March and April are essentially the hurricane season, but they are by no means infrequent in November, December, and May.

PAPER IV.

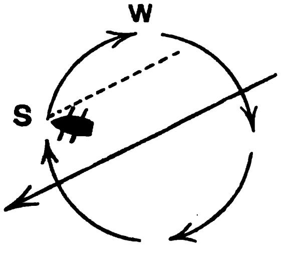
1. The direction of the wind in a cyclone being S.W., state the probable bearing of the centre from the ship in the Southern Hemisphere.

Answer.—In the Southern Hemisphere, the centre bears 8 points to the left of direction of the wind, therefore the centre will bear S.E.

2. And suppose that the wind during the passage of the same cyclone was found to change towards the West, what would be the ship's position with reference to the line of progression of the centre of the cyclone, and what action would you take?

Answer.—The ship is in the right-hand semicircle. Run, keeping the wind, if possible, on the port quarter; and when the barometer rises, if necessary, to keep the ship from going too far from her proper course, heave-to on the starboard tack (see page 408).

Fig. 120.



Example in Illustration.—A ship in lat. 20° S., long. 64° E. (northern part of Southern Indian Ocean, near the Mauritius, see Question 6), with an increasing wind from South, and falling barometer. The wind hauls to S.W., that is, *against the sun;* the ship is, therefore, in the *right-hand semicircle* of the storm, the centre bearing first East and then S.E., or *Eight* points from the wind, reckoned *with the sun,* and the storm is moving towards the S.W. (see Fig. 120 annexed).

3. Under what conditions would the change in the direction of the wind in the cyclone be the reverse of the above?

Answer.—The change in the direction of the wind would be the reverse of that given in Question 2 if the ship and the storm are travelling in the same direction, but the ship going faster than the storm. The change would also be the reverse if the ship were on the other side of the line of progression, but *not* going faster than the storm.

4 and 5. The questions and answers same as in Paper I.

6. Describe the track usually taken by cyclones in the Indian Ocean, near Mauritius, and state the seasons of the year in which they most frequently occur in that region.

Answer.—In that region storms mostly travel towards the S.W.-ward. The season is from December to April, February and March being the worst months.

PAPER V.

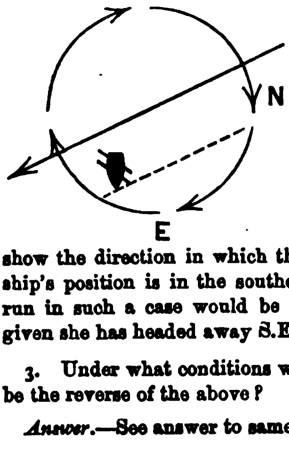
1. The direction of the wind in a cyclone being East, state the probable bearing of its centre from the ship in the Southern Hemisphere.

Answer.—In the Southern Hemisphere the centre bears *Eight* points to the *left* of the direction of the wind; therefore, the centre bears about North.

2. And suppose that the wind during the passage of the same cyclone was found to change toward the N.E., what would be the ship's position with reference to the line of progression of the centre of the cyclone, and what action would you take?

Answer.—Wind backing from E. to N.E., the ship is on the left-hand side of the storm. I would carry sail with the wind on the port side until in a safe position, and then, if necessary, heave-to on the port tack. If the barometer should again fall sail her, if possible, further out.

Fig. 121.



NOTE.—Ship in latitude 24° S., longitude 66° E. (near Mauritius, see Question 6) experiences a wind from the East, which hauls to N.E., or *with the sun*, with a falling barometer. This ship is in the *left-hand semicircle* of the storm, the centre bearing North and N.W., *Eight* points from the wind, also reckoned *with the sun*, and the storm is moving towards the S.W. (see Fig. 121). Now calling the top of your paper the North, sketch a small diagram as in margin above (Fig. 120) with a long arrow to show the direction in which the storm is moving. It will at once be evident that the ship's position is in the southern verge of the storm, in the "dangerous quadrant." To run in such a case would be to cross the advancing front; hence, by the answer just given she has headed away S.E. from the storm's track.

3. Under what conditions would the change in the direction of the wind in the cyclone be the reverse of the above?

Answer.—See answer to same question, Paper I.

4 and 5. The same questions and answers as in Paper I.

6. Describe the track usually taken by cyclones in the Indian Ocean near Mauritius, and state the seasons of the year in which they most frequently occur in that region.

Answer.—In that region storms mostly travel towards the S.W.-ward. The season is from December to April, February and March being the worst months.

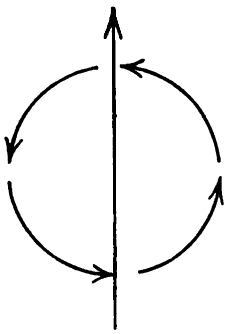
PAPER VI.

1. The direction of the wind in a cyclone being S.S.E., state the probable bearing of its centre from the ship in the Northern Hemisphere.

Answer.—About W.S.W. (in N. Hemisphere eight points to right).

2. And suppose that the wind during the passage of the same cyclone was found to change towards the S.S.W., what would be the ship's position with reference to the line of progression of the centre of the cyclone, and what action would you take?

Fig. 122.



Answer.—The wind veering to the right the ship would be in the right-hand semicircle of storm. Run the vessel with the wind on the starboard quarter, and when the barometer rises, if necessary, to keep the ship from going too far from her proper course, heave-to on the starboard tack. Should the barometer again fall, run her, as before, further out.

Note.—Referring to Question 6 the locality is seen to be the Bay of Bengal, where the average track is N.N.W., but change of wind shows storm going North, diagram (Fig. 122) shows ship as almost out of the dangerous quadrant. By sailing as above (see answer to question) the weather will be found to improve, and perhaps a fair wind may be got. It will be necessary, however, to watch the storm does not recurve to N.E.

3, 4, and 5. The questions and answers same as in Paper I.

6. Describe the track usually taken by cyclones in the Bay of Bengal, and state the season of the year in which they most frequently occur in that region.

Answer.—Those which originate in the north part of the bay usually progress towards N. by W. and N.W. by W. Those which originate near the Andaman Islands (not in the Andaman Sea) progress towards N.N.W. and West; whilst those that occur in the south part of the bay have usually a progressive motion towards the West, or a little *North* of West. The seasons are at the change of the Monsoons, April, May, September, October, also in November; the two latter being the worst months.

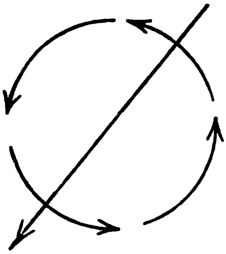
Paper VII.

1. The direction of the wind in a cyclone being West, state the probable bearing of the centre from the ship in the Northern Hemisphere.

Answer.—About North (N. Hemisphere eight points to *right*).

2. And suppose that the wind during the passage of the same cyclone was found to change towards the S.W., what would be the ship's position with reference to the line of progression of the centre of the cyclone, and what action would you take?

Fig. 123.



Answer.—The ship would be in the left-hand side of the line of progression of the centre of the cyclone. I would run the ship, keeping the wind, if possible, on the starboard quarter; and when the barometer rises, if necessary, to keep the ship from going too far from her proper course, heave-to on the port tack.

Note.—According to Question 6 the locality is the China Sea, and the sketch in margin shows that the ship is in the S.E. part of typhoon, and in a hinder quadrant. To avoid the terrible sea of the wake the ship should be kept well out to the S.E.

3, 4, and 5. The questions and answers same as in Paper I.

6. Describe the track usually taken by cyclones in the China Sea, and state the seasons of the year in which they most frequently occur in that region.

Answer.—In this region storms generally travel Westerly to North-Westerly in July and August, and South-Westerly to North-Westerly in the months of September, October, and November.

ORDINARY EXAMINATION.

EXAMINATION PAPER—No. I.

To be used by all Candidates when appearing for Examination for the first time only.

DEFINITIONS.

The Candidate is requested to write at least ten of the following definitions. The writing should be clear, and the spelling not be disregarded.

1. **The Equator** is a great circle passing round the earth at an equal distance from each pole (see page 63, and Fig. 11, page 66).

2. **The Poles** of the earth are the two extremities of its axis, about which it revolves (see Fig. 11, page 66).

3. **A Meridian** is a great circle passing through the poles perpendicular to the equator (see page 65, also Fig. 11, page 66).

4. **The Ecliptic** is a great circle representing the apparent annual path of the sun in the heavens (see page 157).

5. **The Tropics** are two small circles parallel to the equator, one of which is 23° 28′ north of it, and is called the Tropic of Cancer; the other is 23° 28′ south of it, and is called the Tropic of Capricorn.

6. **Latitude** is an arc of a meridian intercepted between the place and the equator, and is reckoned in degrees (°), minutes (′), and seconds (″). (See page 65, also Fig. 11, page 66).

7. **Parallels of Latitude** are small circles parallel to the equator (see page 65, also Fig. 11, page 66).

8. **Longitude** is an arc of the equator intercepted between the "first meridian" and the meridian of the place (see page 65, also Fig. 11, page 66).

9. **The Visible Horizon** is the circle bounding the spectator's view at sea (see page 164).

10. **The Sensible Horizon** is a plane, to which a plumb line is perpendicular, passing through the eye of the observer.

11. **The Rational Horizon** is the great circle in which the plane drawn through the centre of the earth parallel to the sensible horizon meets the celestial concave.

12. **Artificial Horizon.**—A reflector, whose surface is perfectly horizontal, used to observe altitudes on shore.

13. **True Course of a Ship** is the angle which a ship's track makes with a true meridian (see page 75, also Fig. 17, page 76).

14. **Magnetic Course** is the angle which a ship's track makes with the magnetic meridian (see page 75, and Fig. 17, page 76).

15. **Compass Course** is the angle which a ship's track makes with the compass needle (see page 75, also Fig. 17, page 76).

16. **Variation of the Compass** is the angle between the meridian of the place and the magnetic meridian (see page 75, also Fig. 17, page 76).

17. **Deviation of the Compass.**—The angle between the magnetic meridian and the direction of the compass needle, and represents the effect of disturbing forces of iron near it (see page 75, also Fig. 17, page 76).

18. **The Error of the Compass** is the angle between the meridian of the place and the direction of the compass needle (see page 75, also Fig. 17, page 76).

19. **Leeway** is the angle which a ship's track makes with her fore-and-aft line, or keel (see page 75, also Fig. 17, page 76).

20. **Meridian Altitude of a Celestial Object** is the angular height of the object above the horizon when it is on the place of observation.

21. **The Azimuth, or True Bearing** of a heavenly body, is the arc of the horizon between the N. and S. points and a vertical circle passing through the body (see page 163, also Fig. 45, page 172, and Fig. 48, page 174).

22. **The Amplitude** of a heavenly body is the arc of the horizon between the East point and the centre of the object when rising, or the West point when setting (see page 164, also Fig. 45, page 172, and Fig. 48, page 174).

23. **Declination** of a celestial object is the arc of a circle of declination between the object and the equinoctial (see page 159, and Figs. 45 and 48, pages 172 and 174).

24. **Polar Distance** is the arc of a circle of declination between the elevated pole and the object (see page 161, also Fig. 45, page 172, and Fig. 48, page 174).

25. **Right Ascension** of a celestial body is an arc of the equinoctial, or an angle at the pole, between the first point of Aries and the meridian passing through the object (see page 159, and Fig. 48, page 174).

26. **Dip** is the angle through which the sea horizon is depressed in consequence of the elevation of the spectator above the surface of the earth. It is the angle at the eye of the observer between the visible and sensible horizons (see Fig. 40, page 164).

27. **Refraction** is a correction to be applied to the place of a heavenly body on account of the effect of the earth's atmosphere, which bends the rays of light passing through it into a position more nearly vertical, and thus causes the apparent places of the heavenly bodies to be above the true places (see page 164).

28. **Parallax** is the angle subtended at the object by that radius of the earth which is drawn to the place of observation.

Note.—Parallax is a correction to be added to the apparent altitude, or that which is taken on the earth's surface, to make it what it would have been if observed at its centre and estimated from the rational horizon (see page 164).

29. **Semidiameter** of a heavenly body is the angle subtended at the eye of the observer by the radius of the disc (see page 165).

30. **Augmentation of the Moon's Semidiameter** is the apparent increase of the Moon's semidiameter arising from the decreased distance from the Moon as her altitude increases (see page 166).

31. **Observed Altitude** of a heavenly body is its angular distance from the sea horizon read from the arc of the instrument by which the altitude has been measured.

32. **Apparent Altitude.**—When the observed altitude has been corrected for Dip and Semidiameter (if any) the result is the apparent altitude, that is, the apparent angular height of the object's centre above the sensible horizon (see page 168).

33. **True Altitude.**—When the Apparent Altitude has been corrected for Refraction and Parallax (if any) the result is called the True Altitude, that is, the true angular distance of an object's centre above the Rational Horizon (see page 166).

34. **Zenith Distance** is the arc of a vertical circle intercepted between the zenith and the place of the body (see page 163, also Fig. 45, page 172, also Fig. 48, page 174).

35. **Vertical Circles** are great circles passing through the zenith perpendicular to the horizon.

Note.—They are also called *Circles of Altitude*, because altitudes are measured on them, and *Circles of Azimuth*, as marking out all points that have the same azimuth (see page 163).

36. **Prime Vertical** is the vertical circle passing through the East and West points of the horizon (see page 163, also Fig. 45, page 172, also Fig. 48, page 174).

37. **Civil Time** is the time used in ordinary life to record events. It begins at midnight and ends at the following midnight, and its hours are reckoned through twice 12; from midnight to noon, denoted by A.M., and then from noon to midnight, denoted by P.M. (see page 175).

38. **Astronomical Time** is the time used in all astronomical calculations; it begins at noon and ends at the following noon, its hours being reckoned from 0^h to 24^h (see page 175).

39. **Sidereal Time** is the angle at the pole of the heavens between the celestial meridian and an hour circle (or circle of declination) passing through the first point of Aries, measuring from the meridian westward (see page 169).

40. **Mean Time** is the angle at the pole between the celestial meridian and a circle of declination passing through the mean sun, measuring from the meridian westward.

41. **Apparent Time** is the angle at the pole between the celestial meridian and an hour circle (or circle of declination) passing through the place of the sun's centre, measuring from the meridian westward (see page 167).

42. **Equation of Time** is an angle at the pole, or the corresponding arc of the Equinoctial intercepted between the hour circles passing through the places of the true and mean sun. It is the difference between apparent and mean time (see hour circles, page 166, also page 168).

43. **Hour-Angle** of a celestial object is the angle at the elevated pole, or the corresponding arc of the Equinoctial intercepted between the celestial meridian and the hour circle passing through the place of the body.

44. **Complement of an Arc or Angle** is the remainder obtained by subtracting the arc or angle from 90° (see page 39).

45. **Supplement of an Arc or Angle** is the remainder obtained by subtracting the arc or angle from 180°.

FOR SECOND MATE.

1. Multiply 7654 by 95, and 723·36 by 875·52, by common logarithms.
2. Divide 3654000 by 7308, and 174·6015 by 58·2005, by common logarithms.
3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way. pts.	Deviation.	Remarks, &c.
1	W.S.W.	10	8	N.W.	½	11° W.	A point, lat. 37° 3′ N. long. 9° 0′ W., bearing by compass N.E. ¼ E., dist. 15 miles. Ship's head W.S.W. Deviation as per log.
2		11	4				
3		11	4				
4		11	4				
5	N.W. ½ N.	12	2	W.S.W.	¼	17° W.	
6		12	3				
7		12	3				
8		12	2				
9	N.N.W.	9	6	West.	¾	11° W.	
10		9	5				
11		9	5				
12		9	4				
1	N.W. by W.	7	8	S.W. by W.	1¼	20° W.	Variation 22½° W.
2		7	6				
3		7	4				
4		8	2				
5	S.W. ½ S.	9	3	S.S.E.	1	6° W.	
6		8	7				
7		9	3				A current set S.W. by W. ¾ W. (correct magnetic), 8 miles from the time the departure was taken to the end of the day.
8		8	7				
9	W. ½ S.	10	3	S. by W.	½	14° W.	
10		10	2				
11		10	2				
12		10	3				

Correct the courses for deviation, variation, and leeway, and find the course and distance from the given point, and the latitude and longitude in by inspection.

4. 1887, January 1st, in long., 102° 41 W., the observed mer. alt. of the sun's L.L. was 59° 59′ 50″, bearing South, index error + 50″, height of eye 15 feet: required the latitude.

5. In latitude 37° the departure made good was 89·2 miles: required the diff. of long. by Parallel Sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Lat. of A 43° 8′ N. Long. of A 5° 56′ E.
Lat. of B 39 29 N. Long. of B 0 24 W.

7. 1885, January 19th: find the time of high water, A.M. and P.M., at Cherbourg, Christchurch, and Falmouth.

8. 1887, January 1st, at $8^h\ 4^m$ A.M., apparent time at ship, in lat. 50° 32′ N., long. 139° 51′ W., sun's bearing by compass E. by S. ½ S.: required the true amplitude and error of compass; and supposing the variation to be 23° 52′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, January 29th, P.M. at ship, lat. 42° 26′ N., observed altitude sun's L.L. 13° 40′, index corr. — 1′ 14″, height of eye 16 feet, time by chronometer $29^d\ 6^h\ 48^m\ 40^s$, which, on December 1st, 1886, was $11^m\ 22^s{\cdot}3$ *slow* for mean noon at Greenwich, and on January 1st, 1887, was $8^m\ 7^s$ *slow* for mean noon at Greenwich: required the longitude by chronometer.

ADJUSTMENTS OF THE SEXTANT.

The applicant will answer in writing, on a sheet of paper which will be given him by the Examiner, all the following questions, numbering his answers with the numbers corresponding to the questions:—

1. What is the first adjustment of the sextant?
2. How do you make that adjustment?
3. What is the second adjustment?
4. Describe how you make that adjustment?
5. What is the third adjustment?
6. How would you make the third adjustment?
7. In the absence of a screw how would you proceed?
8. How would you find the index error by the horizon?
9. How is it to be applied?
10. Place the index at error of 15 minutes to be added, clamp it, and leave it.

NOTE.—*The Examiner will see that it is correct.*

NOTE.—*For answers to these see pages* 285 *and* 286.

11. The Examiner will then place the zero of the vernier on the arc, not near any of the marked divisions, and the Candidate will read it.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, January 15th, mean time at ship $9^h\ 39^m\ 44^s$ A.M., latitude 23° 39′ S., longitude 127° 52′ W., sun's bearing by compass S. 103° E., observed altitude sun's L.L. 55° 8′ 30″, index error — 2′ 30″, height of eye 12 feet: required the true azimuth and error of the compass; and supposing the variation to be 7° 50′ E.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, January 17th, P.M. at ship, lat. by acct. 36° 2′ N., long. 149° 28′ E., the obs. alt. of the sun's L.L., South of the observer, was 32° 54′ 15″, index error + 2′ 18″, height of eye 22 feet, time by watch $16^d\ 23^h\ 59^m$, which had been found to be $20^m\ 24^s$ *slow* on app. time at ship, the difference of longitude made to the West since the error of watch on app. time at ship was determined was 39′·2: required the latitude by reduction to meridian.

The remaining problems have to be worked on the second day of Examination.

12. 1887, January 16th, A.M. at ship, and uncertain of my position, when a chronometer showed January $15^d\ 22^h\ 16^m\ 1^s$ M.T.G., obs. alt. sun's L.L. 12° 52′ 30″; again, P.M. at ship same day, when chronometer showed January $16^d\ 2^h\ 47^m\ 2^s$, obs. alt. sun's L.L. 14° 1′ 57″, height of eye 17 feet, the ship having made 42 miles on a true N.N.W. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 48° 50′ N. and 49° 30′ N.

CYCLONES, OR REVOLVING STORMS.

The Candidate must answer in writing, on paper supplied to him by the Examiner, the following questions, numbering the answers to correspond with the questions.

Q. 1. The direction of the wind in a cyclone being S.E., state the probable bearing of its centre from the ship in the Northern hemisphere.

Q. 2. And suppose that the wind during the passage of the same cyclone was found to change towards South, what would be the ship's position with reference to the line of progression of the centre of the cyclone, and what action would you take?

Q. 3. Under what conditions would the change in the direction of the wind in the cyclone be the reverse of the above?

Q. 4. What are the usual indications of a ship being on the line of progression of the centre of a cyclone?

Q. 5. What are the usual indications that a ship is (*a*) approaching the centre of a cyclone? (*b*) receding from it?

Q. 6. Describe the track usually taken by cyclones in the North Atlantic, and state the seasons of the year in which they most frequently occur in that region.

Candidates for Only Mates, First Mates, and Masters' certificates will be required to give in writing replies to the following questions, *in addition* to those required of Candidates for Second Mates' Certificates.

1. How do you find the index error by the sun?

2. The reading being $\left\{\begin{matrix} 31' \ 20'' \ \textit{on} \\ 32 \ \ 10 \ \ \textit{off} \end{matrix}\right\}$ What is the index error, and how do you apply it?

3. What proof have you that these measurements or angles have been taken with tolerable accuracy?

NOTE.—*See page* 286 *for answers to the above.*

CHART WORK FOR ONLY AND FIRST MATE.

Using the outline Magnetic English Channel Chart. Var. 18° W.

1. Using Deviation Card No. I, find the course to steer from Cape La Heve (or A) to the Needles (or B); also the distance.

2. With the ship's head on the above-named compass course, Cape La Heve (or C) bore by compass S. by E. ¼ E., and Fecamp (or D) bore by the same compass S.E. by E. ¼ E.: find the ship's position.

3. With the ship's head as above by compass (E) Cape de Cayeux bore by compass E. by N. ¼ N., and after continuing the same course 15 miles it bore S.E. ¼ E.: find the position of the ship, and her distance from E at the second bearing.

ADDITIONAL FOR MASTER.

4. Find the course to steer by compass from Cape La Heve to the Needles (see Question 1) to counteract the effect of a current which set true W. ¼ S. at the rate of 3 miles an hour, the ship making by log 9 miles an hour; also the distance the ship would make good in 3 hours, and also in 1 hour, towards the Needles.

5. 1885, June 14th, at 11^h 59^m A.M., being off the Needles Point, took a cast of the lead: required the correction to be applied before comparing the soundings.

To be written.

6. What do you understand those small numbers to indicate that you see placed about the chart, and at what time of tide?

Answer.—The depth of water in feet or fathoms at low water of ordinary spring tides.

7. What do the Roman numerals indicate that are occasionally seen near the coasts and in harbours?

Answer.—The time of high water at that place at full and change of the moon.

8. How would you find the time of high water at any place, the *Admiralty Tide Tables* not being at hand, nor any other Tables available?

Answer.—To the time of high water at full and change add 49 minutes for every day elapsed since full or change; the result is the P.M. time of high water.

Or thus:—To the time of the moon's meridian passage add the time of high water at full and change; the sum is the P.M. time of high water.

13. 1887, January 24th, the observed meridian altitude of star α Tauri (*Aldebaran*) was 52° 36′, bearing South, index correction — 23″, height of eye 20 feet: required the latitude.

DEVIATION OF THE COMPASS.

N.B.—*The Candidate is to answer correctly at least eight of such of the following questions as are marked with a cross by the Examiner. The Examiner will not mark less than twelve.*

1. What do you mean by Deviation of the Compass?

A. The deflection of the compass needle from the magnetic meridian caused by the attraction of the iron of the ship (see page 75).

2. How do you determine the deviation (*a*) when in port and (*b*) when at sea?

A. By bringing the ship's head successively upon each of the thirty-two points of the Standard Compass, or on each alternate point, and then (*a*) by taking reciprocal simultaneous bearings; or by the observer on board taking the bearings of a distant object whose correct magnetic bearing is known, or of some conspicuous object in a line with figures on a dock wall. (*b*) At sea, by amplitudes and azimuths and the known variation at the place of the ship.

3. Having determined the deviation with the ship's head on the various points of the compass, how do you know when it is easterly and when westerly?

A. When the *correct* magnetic bearing of the distant object is to the *right* of the reading of the compass on board the deviation is easterly, when to the *left*, westerly.

4. Why is it necessary, in order to ascertain the deviations, to bring the ship's head in more than one direction?

A. Because the deviation changes as the direction of the ship's head is altered.

5. For accuracy, what is the least number of points to which the ship's head should be brought?

A. Eight points, equally distributed round the compass; if the deviations be known on the four quadrantal points, N.E., S.E., S.W., and N.W., with the aid of NAPIER's diagram an approximate result may be obtained.

6. How would you find the deviation when sailing along a well known coast?

A. Take the compass bearing of two known objects when in one; the correct magnetic bearing may then be taken from the chart, and the difference will be the deviation for the point the ship's head was at when the bearing was taken.

7. In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 86° W.		South	S. 64° W.	
N.E.	S. 79 W.		S.W.	S. 72 W.	
East	S. 69 W.		West	S. 89 W.	
S.E.	S. 65 W.		N.W.	N. 80 W.	

8. With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—W.N.W.; N.N.E.; E.S.E.; S.S.W.

Compass courses:—

9. Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—N.N.W.; E.N.E.; S.S.E.; W.S.W.

Magnetic courses:—

10. You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at N.W. by W., find the bearings, correct magnetic.

Compass bearings:—E. by S. ¼ S. and N. ½ E.

Bearings, Magnetic:—

11. Name some suitable objects by which you could readily obtain the deviation of the compass when sailing along the coasts of the English Channel.

The South Foreland lighthouses in one, bearing W. by N., *correct* magnetic; Portland lights in one N.N.W. ¾ W.; Prawl Point and Start lighthouse in one, and Lizard lights in one; or any prominent lighthouses or beacons in either channel.

12. Do you expect the deviation to change; if so, state under what circumstances?

A. Yes, it changes rapidly for several months after the ship is launched, an alteration also takes place by change of magnetic latitude, and in ships running long upon one course and then changing the course, by the heeling of the ship, and by taking in a cargo of iron.

13. How often is it advisable to test the accuracy of your table of deviations?

A. At every possible opportunity.

14. State briefly what you have chiefly to guard against in selecting a position for the compass.

A. Elongated iron, especially if vertical, such as stanchions, davits, capstan, spindles, funnels, ventilating shafts, &c., and the compass should be as far removed as possible from transverse bulk heads.

15. The compasses of iron ships are more or less affected by what is termed the heeling error; on what courses does this error vanish, and on what courses is it the greatest?

A. It vanishes ween the ship's head is East or West by compass, and is greatest when the ship's head by compass is North or South.

16. State to which side of the ship, in the majority of cases, is the North point of the compass drawn in the Northern hemisphere; and what effect has it on the assumed position of the ship when she is steering on Northerly, and also on Southerly courses?

A. The North point of the compass is drawn to the windward side in the majority of cases. The effect of this is to throw the ship to windward of her supposed position on Northerly courses, and to leeward on Southerly courses.

17. The effect being as you state, on what courses would you keep away, and on what courses would you keep closer to the wind, in order to make gook a given compass course?

A. Keep her away on Northerly courses; but keep close to the wind on Southerly courses.

18. Does the same rule hold good in both hemispheres with regard to the heeling error?

A. No; the above rules are generally reversed in the southern hemisphere; but it is recommended, in order to determine it, that observations be made in every ship.

19. Your steering compass having a large error, how would you proceed to correct that compass by compensating magnets and soft iron in order to reduce the error within manageable limits?

A. Draw two chalk lines on the deck, at right-angles to one another, one fore-and-aft and one athwartship, intersecting at a point under the centre of the compass.

The ship being perfectly upright bring her head either North or South (correct magnetic); then place a magnet athwartship with the middle of its length exactly on the fore-and-aft line (either before or abaft the compass), and the N. marked end (*red* pole) directed to that side of the ship towards which the N. end of the needle appears to be drawn. Move the magnet to or from the intersection of the chalk lines until the compass shows correct magnetic North or South, and fix the magnet to the deck. Now bring the ship's head East or West (correct magnetic), place a magnet on the deck in a fore-and-aft direction (either on the port or starboard side of the binnacle), the middle of the magnet on the athwartship line and at right-angles to it, having the N. marked end (*red* pole) of the magnet forward or aft according as the N. or *red* end of the compass needle is drawn forward or aft. Move the magnet to or from the compass until the ship's head is East or West *by the compass.* This adjustment does not remain perfect when the ship changes her latitude owing to part of the deviation being caused by vertical iron, the disturbing power of which varies with change of position—it may be compensated by a soft iron bar placed vertically before the compass (see pages 358-360).

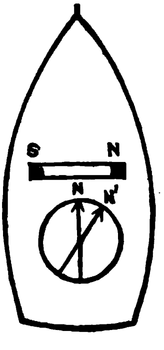
To compensate the force arising from the inductive magnetism of horizontal iron the ship's head is brought to one of the quadrantal points, viz.:—N.E., S.E., S.W., or N.W. (correct magnetic); then, if, as is generally the case, the deviation is Easterly when the ship's head is N.E. or S.W., and westerly when the ship's head is N.W. and S.E., place two soft iron correctors, one on the port side and the other on the starboard side, and at equal distances, and in the same horizontal plane as the compass; move them to or from the compass till the needle points correctly. Otherwise, the compensation may be effected by means of two brass boxes attached one on each side of the binnacle, which are filled with soft iron chain until the error is corrected (see page 361). This last compensation remains unaltered by change of ship's geographical position.

NOTE.—Candidates for Masters' Certificates are now required to draw diagrams similar to those which follow, showing the positions in which the bar magnets and soft iron correctors are placed, as described in answer to No. 19 Question; also to show the position of the bar magnet which compensates the heeling error alluded to in No. 17 Question. He must also write a short description of the diagrams. The Examiner will supply a flat pattern of a ship for the use of the Candidates.

DESCRIPTION AND EXPLANATION OF DIAGRAMS.

Figs. 124 and 125 are diagrams intended to show the method of compensating for semicircular deviation caused by sub-permanent magnetism.

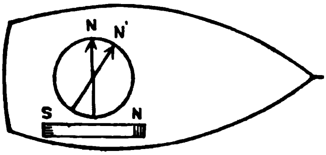
Fig. 124.



In Fig. 124 the ship's head is placed correct magnetic North. The N. marked end of the compass needle is supposed to be drawn to starboard, as at N'. The middle of the magnet's length is placed on the fore-and-aft line, the N. marked, or *red*, pole toward the starboard side, and is moved to or from the compass until the N. marked end, or *red* pole, of the magnet repels, and the other, or S. end, attracts the N., or *red*, end of the compass needle to N. The magnet is then fixed to the deck.

(For example, where the N. end of compass needle is drawn to *port*, and how to compensate in this instance, see Fig. 91, page 360).

Fig. 125.



In Fig. 125 the ship's head is placed (correct magnetic) East. The N., or *red*, end of the compass needle is drawn towards the bow, N' in Fig. 125. The centre of another magnet is placed on the 'thwartship line, with the N. marked, or *red*, end towards the bow, and is moved to or from the compass until the N., or *red*, end of the magnet repels, and the other, or S. (*blue*), end attracts the N., or *red*, end of the compass needle back to N.

(When N. end of needle is attracted towards the stern, and how it is compensated, see Fig. 91, page 360).

Fig. 126.

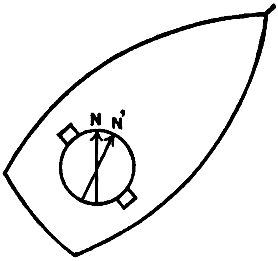
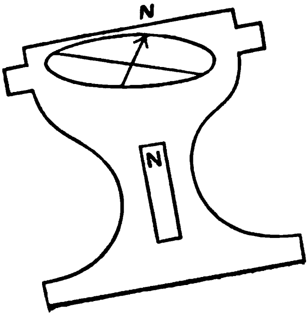


Fig. 126 is a diagram intended to show the method of compensating for quadrantal deviation arising from induced magnetism in horizontal soft iron. In this instance it is placed N.E., correct magnetic, and the position of the soft iron correctors on the port and starboard sides to compensate a *positive* quadrantal deviation, that is, the quadrantal deviation of almost every ship, viz., *Easterly* in the N.E. and S.W. quadrants, and *Westerly* in the N.W. and S.E. quadrants. In the very unusual case where the deviation is Westerly on N.E. and S.W. points, or Easterly on the S.E. and N.W., and large, the correctors, or chain boxes, should be placed on the fore-and-aft ends of the binnacle (see page 360).

Although a ship's compasses may be corrected by the above methods, they can only be depended upon so long as she remains upright. Besides the ordinary deviation of the compass there is a deviation caused by the heeling of iron ships, which may increase or decrease the deviation observed when the ship is upright. The heeling error arises partly from the transverse iron (such as beams) becoming magnetic, partly on vertical force arising from sub-permanent magnetism, combined with that from vertical induction in vertical soft iron. The mechanical correction of the heeling error is made by a magnet placed in a vertical position immediately below the centre of the compass card. The ship's head is to be placed North and South, correct magnetic; she is then heeled over about 10° to port and to starboard, and the magnet raised or lowered until the compass points correctly. In the majority of cases it is found that in the Northern hemisphere the North end of the compass needle is drawn to the highest side of the ship, while in the Southern hemisphere the South end of the compass needle is drawn to the highest side. Care must be taken to have the N. or S. end uppermost, according as the N. or S. end of the compass needle is drawn to the highest side of the ship.

Fig. 127.



In Fig. 127 the ship's head is placed correct magnetic North, and shows the effect upon the compass when the ship heels to port in the Northern hemisphere, the North end of the compass needle being attracted to the highest side of the ship; the magnet with its North end uppermost repels the North end of the compass needle, and attracts the South end, and brings the needle to its proper position (see page 363).

EXAMINATION PAPER—No. II.

FOR SECOND MATE.

1. Multiply 50030 by 800, and 41375 by 48, by common logarithms.

2. Divide 273864 by 9·1288, and 900009 by 9, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way. pts.	Deviation.	Remarks, &c.
1	S.E. by E.	13	2	N.	0	11° E.	A point, lat. 47° 31′ N., long. 52° 33′ W., bearing by compass W.S.W., dist. 18 miles. Ship's head S.E. by E. Deviation as per log.
2		13	3				
3		12	5				
4		13					
5	S.E.	11		E.N.E.	½	9° E.	
6		10	5				
7		10	4				
8		11	1				
9	E. by N.	8	8	S.E. by S.	1	17° E.	
10		9	2				
11		9					
12		9					
1	E.N.E.	6	8	S.E.	1½	15° E.	Variation 28° W.
2		6	7				
3		6	5				
4		7					
5	S.S.E.	5	8	E.	2	7° E.	
6		5	8				
7		6	4				
8		6					A current set S. by E. (correct magnetic) 12 miles, from the time the departure was taken to the end of the day.
9	S.E. by S.	7		E. by N.	1¼	8° E.	
10		7	3				
11		7	4				
12		7	3				

4. 1887, February 1st, in longitude 78° 14′ E., the observed meridian altitude of sun's L.L. was 78° 4′ 10″, bearing South, index error + 55″, height of eye 12 feet: required the latitude.

5. In latitude 75° 30′ N., the departure made good was 390·1 miles: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A	15° 55′ S.	Longitude of A	5° 44′ W.
Latitude of B	55 59 S.	Longitude of B	67 16 W.

7. 1885, February 8th: find the time of high water A.M. and P.M. at Filey Bay, Milford Haven, Cromarty, Penzance, and Calcutta, longitude 88° E.

8. 1887, February 20th, at $6^h\ 9^m$ P.M., apparent time at ship, latitude 11° 58′ S., longitude 179° 42′ E., sun's bearing by compass S.W. by W. ½ W.: required the true amplitude and error of compass; and supposing the variation to be 10° 20′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, February 10th, A.M. at ship, latitude 50° 48′ N., observed altitude sun's L.L. 9° 10′ 50″, index correction — 3′ 20″, height of eye 18 feet, time by chronometer February $9^d\ 9^h\ 59^m\ 25^s$, which, on January 10th, was $34^m\ 12^s$ *fast* for mean noon at Greenwich, and *losing* $10^s{\cdot}8$ daily: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, February 16th, A.M. at ship, latitude 51° 2' N., longitude 140° 34' W., the sun's bearing by compass S. 36° 20' E., observed altitude sun's L.L. 7° 16' 40", index correction — 6' 10", height of eye 15 feet, when a chronometer showed February $16^d 5^h 59^m 51^s$, mean time at Greenwich: required the true azimuth and error of the compass from the altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 25° W.: required the deviation for the position of the ship's head.

11. 1887, February 15th, A.M. at ship, latitude account 55° 59' S., longitude 54° 18' E., observed altitude of sun's L.L., North of observer, was 46° 22' 10", index correction — 1' 50", height of eye 19 feet, time by chronometer February $14^d 20^h 5^m$, which was $3^m 21^s$ *slow* on mean time at Greenwich: required the latitude by reduction to meridian.

12. 1887, February 3rd, A.M. at ship, and uncertain of my position, when a chronometer showed February $2^d 10^h 9^m 2^s$ M.T.G., observed altitude sun's L.L. 19° 50'; again, P.M. at ship same day, when chronometer showed February $2^d 15^h 39^m 53^s$, obs. alt. sun's L.L. 11° 5', height of eye 18 feet, the ship having made 36 miles on a true E. ¾ N. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 47° 10' N. and 47° 40' N.

CYCLONES, OR REVOLVING STORMS.

1. The direction of the wind in a cyclone is North, state the probable bearing of the centre from the ship in the Northern hemisphere.

2. And suppose that the wind during the passage of the same cyclone was found to change to N.W., what would be the ship's position with reference to the line of progression of the centre of the cyclone, and what action would you take?

3. Under what conditions would the change in the direction of the wind in the cyclone be the reverse of the above?

4. What are the usual indications of a ship being on the line of progression of the centre of a cyclone?

5. What are the usual indications that the ship is (*a*) approaching the centre of a cyclone? (*b*) receding from it?

6. Describe the track usually taken by cyclones in the West Indies, and state the seasons of the year in which they most frequently occur in that region.

CHART WORK FOR ONLY AND FIRST MATE.

Using outline English Channel Chart (Magnetic). Var. 18° W.

I. Using Deviation Card No. I, find the course to steer by compass from (A) the Needles to (B) Cape Barfleur, also the distance.

II. With the ship's head on the above compass course (C) Christchurch bore by compass N. by W. ½ W., also (D) St. Catherine's Point bore S.E. by E. ¾ E. by the same compass: find the ship's position.

III. With the ship's head on the above compass course (E) St. Catherine's Point bore by compass E. by S. ½ S., and after continuing the same course 15 miles it bore N.E. ½ E.: find the position of the ship and her distance from E at the second observation.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from the Needles to Cape Barfleur (see Question I) to counteract the effect of a current which set S.W. (true) at the rate of 2½ miles per hour, the ship making by log 8 miles per hour; also the distance the ship would make good in 4 hours, and in 1 hour towards Cape Barfleur.

V. 1885, February 9th, at $6^h 23^m$ P.M., mean time at ship, being off Cape Barfleur, took a cast of the lead: required the correction to be applied to the soundings.

13. 1887, February 12th, the observed meridian altitude of star Procyon, South of observer, was 77° 18' 10", index correction + 19", height of eye 16 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation:—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 34° E.		South	S. 43° E.	
N.E.	S. 58 E.		S.W.	S. 31 E.	
East......	S. 62 E.		West	S. 17 E.	
S.E.......	S. 52 E.		N.W.	S. 15 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—N.E. by E. ½ E.; W. ¼ S.; W. ¾ N.; E. by S. ½ S.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—W. by N. ½ N.; N.E. ¾ N.; S.W. ¼ S.; S.E. by S.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at W. ½ S., find the bearings, correct magnetic.

Compass bearings:—N. 79° W. and S. 19° W.

Bearings, magnetic:—

EXAMINATION PAPER—No. III.

FOR SECOND MATE.

1. Multiply 3914 by 600, and 8497·5 by 24·4, by common logarithms.
2. Divide 666·666 by 8·88, and 33333333 by 67420, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	S.S.E.	5	6	East.	2¼	3° E.	A point, in lat. 62° N., long. 150° E., bearing by compass W. *b* S. ¼ S., dist. 17 miles. Ship's head S.S.E. Deviation as per log.
2		5	6				
3		5					
4		4	8				
5	S.S.W. ½ W.	4	7	West.	2¾	4° W.	
6		4	8				
7		5	2				
8		5	3				
9	W.S.W.	5		South.	2½	9° W.	
10		6					
11		6	5				
12		6	5				
1	W. ½ N.	6	6	N. by E.	0	11° W.	Variation 31° E.
2		7					
3		6	4				
4		6					
5	East.	4	6	S.S.E.	2½	10° E.	
6		5					
7		4	8				
8		4	6				A current set N.N.E. (correct magnetic) 21 miles, from the time the departure was taken to the end of the day.
9	E.S.E.	4		S. by W.	0	9° E.	
10		4	5				
11		4	5				
12		5					

4. 1887, March 20th, in longitude 173° 18′ W., the obs. mer. alt. of the sun's L.L. was 89° 37′, bearing North, index error + 4′ 27″, height of eye 18 feet: required the latitude.

5. In latitude 86° 36′ S., the departure made good was 246·75 miles: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 34° 28′ S. Longitude of A 18° 28′ E.
Latitude of B 23 0 S. Longitude of B 41 57 W.

7. 1885, March 4th, find the time of high water, A.M. and P.M., at Quillebœuf, Havre, Poole, Yarmouth Roads, Lerwick, and Beaumaris.

8. 1887, March 6th, at $5^h\,31^m\,52^s$ P.M. apparent time at ship, in latitude 52° 12′ N., longitude 138° 54′ W., sun's bearing by compass W. by S. ½ S.: required the true amplitude and error of compass; and supposing the variation to be 24° E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, March 31st, A.M. at ship, latitude 26° 9′ N., observed altitude sun's L.L. 29° 19′ 30″, index correction — 9′ 10″, height of eye 26 feet, time by chronometer $31^d\,0^h\,4^m\,50^s$, which, on December 31st, 1886, was $1^h\,2^m\,55^s{\cdot}8$ *fast* for mean noon at Greenwich, and *gaining* $5^s{\cdot}8$ daily: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, March 10th, A.M. at ship, latitude 42° 41′ S., longitude 147° 41′ E., the sun's bearing by compass S. 108° 37′ E, observed altitude sun's L.L. 17° 57′ 40″, index correction 0, height of eye 19 feet, when a chronometer showed March $9^d\,9^h\,43^m\,5^s$ mean time at Greenwich: required the true azimuth and error of the compass from altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 10° 50′ E.: required the deviation for the position of the ship's head.

11. 1887, March 25th, P.M. at ship, latitude by account 20° 1′ N., longitude 89° 10′ E., the observed altitude of the sun's L.L., South of the observer, was 71° 6′ 30″, index correction + 3′ 30″, height of eye 18 feet, time by chronometer March $24^d\,18^h\,22^m$, which was $2^m\,19^s$ *fast* on mean time at Greenwich: required the latitude by reduction to meridian.

12. 1887, March 27th, A.M. at ship, and uncertain of my position, when a chronometer showed March $27^d\,10^h\,26^m\,24^s$ M.T.G., observed altitude sun's L.L. 36° 38′ 50″; again, P.M. at ship same day, when chronometer showed March $27^d\,16^h\,37^m\,10^s$, observed altitude sun's L.L. 15° 15′ 20″, height of eye 22 feet, the ship having made 28 miles on a true S. ½ E. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 51° 30′ N., and 51° 0′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using English Channel Chart (Magnetic). Var. 21° W.

I. Using Deviation Card No. I, find the course to steer by compass from East Point of Guernsey to Berry Head.

II. With the ship's head on the above-named compass course Hanois, West Point of Guernsey, bore by compass S. 28° W., and Casquets bore S. 82° E. by the same compass: find the ship's position.

III. With the ship's head as above Casquets bore by compass N. 62° E., and after continuing on the same course 12 miles it bore S. 63° E.: find the position of the ship, and her distance from the Casquets at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from the East end of Guernsey to Berry Head (see Question I) to counteract the effect of a current which set E. ½ S. (magnetic) at the rate of 3½ miles per hour, the ship making by log 9 miles per hour; also the distance the ship then makes good in 3 hours, and in 1 hour, towards Berry Head.

V. 1885, March 10th, $3^h\,42^m$ P.M. mean time at ship, being off Torbay, took a cast of the lead: required the correction to be applied before comparing the soundings.

13. 1887, March 19th, the obs. mer. alt. of star α Bootis (*Arcturus*), North of observer, was 36° 10′ 20″, index correction + 2′ 42″, height of eye 20 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 67° E.		South	S. 72° E.	
N.E.	East.		S.W.	S. 46 E.	
East	N. 85 E.		West	S. 45 E.	
S.E.	N. 87 E.		N.W.	S. 52 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—N.E. ½ E.; S.W. by W.; W. by S. ¾ S.; S.S.E. ¼ E.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—S.E. by E. ¼ E.; N.E. by E. ½ E.; N.W. by W. ¾ W.; N.N.W.

Correct magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with ship's head at N. 24° E., find the bearings, correct magnetic.

Compass bearings:—W. ¾ S. and E.N.E.

Bearings, magnetic:—

EXAMINATION PAPER—No. IV.

FOR SECOND MATE.

1. Multiply 12500 by 320·2, and 145·544 by 500, by common logarithms.
2. Divide 100784·3 by 987·24, and 8712360 by 80670, by common logarithms.
3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	S.W. ½ W.	14	5	S.E.	0	6° W.	A point, lat. 50° 12′ S., long. 179° 40′ W., bearing by compass N. ¾ W. dist. 19 miles. Ship's head S.W. ½ W. Deviation as per log.
2		14	2				
3		14	6				
4		14	7				
5	N. ¾ E.	4		E.N.E.	3¼	3° E.	
6		3	6				
7		3	6				
8		3	8				
9	S. by E. ½ E.	2	4	S.W. ½ W.	2¾	6° E.	
10		2	3				
11		2	3				
12		2					
1	W. by S.	12	2	S. by W.	¼	14° W.	Variation 14° E.
2		12	4				
3		12	6				
4		12	8				
5	E.N.E.	3		S.E.	2½	19° E.	
6		2	3				
7		3	4				A current set the ship S.W. ¼ W., (correct magnetic), 42 miles, from the time the departure was taken to the end of the day.
8		3	3				
9	S.S.W. ½ W.	5	6	S.E.	1¾	4° W.	
10		5	7				
11		5	3				
12		5	4				

4. 1887, April 1st, in longitude 82° 47′ W., observed meridian altitude sun's L.L. was 48° 42′ 30″ bearing South, index error + 1′ 42″, height of eye 18 feet: required the latitude.

5. In latitude 86° 12′ N., the departure made good was 394·5 miles: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A	52° 9′ S.	Longitude of A	12° 15′ W.
Latitude of B	42 0 N.	Longitude of B	17 14 W.

7. 1885, April 8th: find the time of high water, A.M. and P.M., at Ecrehous, Blakeney, Portree, Llanelly, Cardiff, and New Ross.

8. 1887, April 28th, at $5^h\ 14^m\ 2^s$ P.M., apparent time at ship, in latitude 38° 19′ S., longitude 88° 48′ E., sun's bearing by compass N.W. by W.: required the true amplitude and error of compass; and supposing the variation to be 19° 10′ W.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, April 15th, P.M. at ship, latitude 37° 49′ S., observed altitude sun's L.L. 26° 27′ 30″, index correction — 49″, height of eye 13 feet, time by chronometer $15^d\ 4^h\ 25^m\ 3^s$, which, on February 3rd, was $2^m\ 35^s{\cdot}4$ *fast* for mean noon at Greenwich, and *losing* $11^s{\cdot}3$ daily: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, April 17th, P.M. at ship, latitude 39° 50′ N., longitude 1° 35′ E., the sun's bearing by compass West, observed altitude sun's L.L. 42° 10′, index correction — 45″, height of eye 14 feet, when a chronometer showed April $17^d\ 2^h\ 43^m\ 25^s$, mean time at Greenwich: required the true azimuth and error of the compass from the altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 19° 50′ W.: required the deviation for the position of the ship's head.

11. 1887, April 19th, A.M. at ship, latitude by account 46° 15′ N., longitude 178° 12′ E., observed altitude sun's L.L., South of observer, 54° 7′, index correction + 2′ 12″, height of eye 20 feet, time by chronometer April $18^d\ 11^h\ 40^m$, which was $2^m\ 16^s$ *fast* on mean time at Greenwich: required the latitude by reduction to meridian.

12. 1887, April 6th, P.M. at ship, and uncertain of my position, when a chronometer showed April $6^d\ 1^h\ 17^m\ 25^s$ M.T.G., observed altitude sun's L.L. 45° 7′ 10″; again, P.M. at ship same day, when chronometer showed April $6^d\ 4^h\ 23^m\ 24^s$, observed altitude sun's L.L. 24° 52′ 10″, height of eye 18 feet, the ship having made 46 miles on a true W. by N. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 50° 20′ N. and 50° 50′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using outline English Channel (Magnetic) Chart. Var. 19° W.

I. Using Deviation Card No. I, find the course to steer by compass from the Needles to the Start, also the distance.

II. With the ship's head on the above-named compass course Christchurch bore by compass N. 16½° W., and Anvil Point light bore N. 89° W. by the same compass: find the ship's position.

III. With the ship's head as above, St. Catherine's light bore by compass S. 84° E., and after continuing the same course 21 miles it bore N. 73° E.: find the ship's position and distance from St. Catherine's light at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from the Needles to the Start to counteract the effect of a current which set W. ½ N., magnetic, at the rate of 3 miles an hour, the ship making by log 9 miles an hour; also the distance the ship would make good per hour towards the Start.

V. On June 14th, 1885, at $11^h\ 29^m$ A.M., being off Portland Breakwater by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, April 12th, the observed meridian altitude of star Spica, South of observer, was 20° 58′ 40″, index correction — 45″, height of eye 25 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation:—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 4°W.		South	S. 7°E.	
N.E.	S. 27 W.		S.W.	S. 33 E.	
East......	S. 36 W.		West	S. 35 E.	
S.E.	S. 30 W.		N.W.	S. 22 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—E.S.E.; S.W. ½ W.; N. ¼ W.; E. by N. ¾ N.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—N.W. by N.; N.E. ½ N.; W. by S. ¾ S.; N. ¼ E.

Correct magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at E. by N., find the bearings, correct magnetic.

Compass bearings:—N.W. and W.S.W.

Bearings, magnetic:—

EXAMINATION PAPER—No. V.

FOR SECOND MATE.

1. Multiply 10003 by 110, and 1·986004 by 27380, by common logarithms.
2. Divide 66889·2 by 99·7, and 78·6332000 by 17320, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way. pts.	Deviation.	Remarks, &c.
1	S.E. ½ E.	14		S.W.	0	8° E.	A point in lat. 64° 2′ S. long. 178° 21′ E., bearing by compass W. by S. ¾ S., dist. 23 miles. Ship's head S.E. ½ E. Deviation as per log.
2		14					
3		14	4				
4		13	6				
5	E. by S. ¾ S.	4	4	N.E.	3	14° E.	
6		4	2				
7		4	2				
8		4	2				
9	W.N.W.	4		North.	2¾	19° W.	
10		3					
11		3					
12		3					
1	N.E. ¼ N.	9	2	N.N.W.	¼	8° E.	Variation 37° E.
2		9	2				
3		9	2				
4		9	4				
5	S.W. by S.	8	4	W.N.W.	1½	10° W.	
6		8	4				
7		7	2				
8		7					A current set N.E. ¼ E. correct magnetic 48 miles from the time the departure was taken to the end of the day.
9	N.N.W.	5		West.	2	11° W.	
10		4					
11		4					
12		4					

4. 1887, May 8th, in longitude 105° 17′ W., the obs. mer. alt. of the sun's L.L. was 76° 3′, bearing North, index error — 1′ 27″, height of eye 10 feet: required the latitude.

5. In latitude 84° 16′ N. the departure made good was 500·25 miles: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 39° 39′ N.   Longitude of A 51° 51′ E.
Latitude of B 27 27 N.   Longitude of B 33 33 E.

7. 1885, May 29th: find the time of high water, A.M. and P.M., at Loch Ryan, Tarn Point, Berwick, St. Malo, and Dungeness.

8. 1887, May 21st, at 7^h 29^m A.M., apparent time at ship, in latitude 45° 53′ S., longitude 50° 39′ E., sun's bearing by compass N.E. ¼ E.: required the true amplitude and error of compass; and supposing the variation to be 31° 50′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, May 22nd, A.M. at ship, latitude 43° 25′ N., observed altitude sun's L.L. 32° 8′, index correction + 47″, height of eye 15 feet, time by chronometer 21^d 21^h 6^m 10^s, which, on February 24th, was $12^s·6$ *slow* for mean noon at Greenwich, and on April 1st was 2^m 45^s *fast* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, May 25th, P.M. at ship, latitude 41° 58′ N., longitude 96° 1′ W., the sun's bearing by compass N. 118° 30′ W., observed altitude sun's L.L. 40° 40′ 40″, index correction + 2′ 15″, height of eye 12 feet, when a chronometer showed May 25^d 9^h 53^m 51^s mean time at Greenwich: required the true azimuth and error of the compass from altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 10° 30′ E.: required the deviation for the position of the ship's head.

11. 1887, May 10th, A.M. at ship, latitude by account 28° 13′ S., longitude 112° 15′ W., the observed altitude of the sun's L.L., North of the observer, was 43° 35′ 20″, index correction — 6′ 12″, height of eye 19 feet, time by chronometer May 10^d 8^h 0^m 16^s, which was 9^m 40^s *fast* on mean time at Greenwich: required the latitude by reduction to meridian.

12. 1887, May 30th, A.M. at ship, and uncertain of my position, when a chronometer showed May 29^d 19^h 21^m 15^s M.T.G., observed altitude sun's L.L. 23° 42′ 10″; again, P.M. at ship same day, when chronometer showed May 30^d 2^h 7^m 5^s, observed altitude sun's L.L. 56° 45′, height of eye 15 feet, the ship having made 49 miles on a true West course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 50° 0′ N. and 50 30′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline Chart (Magnetic) English Channel.

I. Using Deviation Card No. I, find the course to steer by compass from (A) the Smalls to (B) Saltees Lightship, also the distance.

II. With the ship's head on the above-named compass course St. David's Head bore by compass E. by N., and the Smalls S.E. by S.: find the ship's position.

III. With the ship's head as above St. Ann's Head bore by compass E. by N. ¾ N., and after continuing on the same course 11 miles it bore E. ¾ S.: find the position of the ship, and her distance from St. Ann's Head at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from the Smalls to the Saltees Lightvessel (see Question I) to counteract the effect of a current which set South (correct magnetic) at the rate of 2 miles per hour, the ship making by log 7 miles per hour; also the distance the ship would make good in 3 hours towards the Saltees Lightvessel.

V. 1885, May 8th, at 2^h 12^m P.M. mean time at ship, took a cast of the lead off the Smalls: required the correction to be applied to the soundings.

13. 1887, May 10th, the observed meridian altitude of star Spica, North of observer, was 70° 10′ 25″, index correction + 42″, height of eye 22 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	East.		South	N. 85°E.	
N.E.	S. 78°E.		S.W.	N. 63 E.	
East......	S. 70 E.		West	N. 64 E.	
S.E.	S. 71 E.		N.W.	N. 74 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct Magnetic courses:—N.N.E. ¾ E.; N. 84° W.; S. 72° E.; S.W. by W. ½ W.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—N.N.W. ½ W.; N. 64° E.; S.E. ¾ E.; S. 39° W.

Correct magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above; with the ship's head at S. 87° E., find the bearings, correct magnetic.

Compass bearings:—S. 15° W. and N. 72° W.

Bearings, magnetic:—

EXAMINATION PAPER—No. VI.

FOR SECOND MATE.

1. Multiply 987 by 543, and 12·19118 by 510000, by common logarithms.
2. Divide 963766782 by 7462103, and 999999 by 10101, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	E. by S.	4	3	S. by E.	3¼	15° E.	A point, lat. 56° 12′ N. longitude 135° 40′ W., bearing by compass W.S.W., dist. 23 miles. Ship's head E. by S. Deviation as per log.
2		4	4				
3		4	3				
4		4					
5	S.E. by E.	5	6	S. by W.	1¼	12° E.	
6		5	8				
7		5	6				
8		5					
9	S. by E.	5	7	S.W. by W.	1½	4° E.	
10		5	8				
11		6					
12		6	5				
1	E. ¾ S.	6	4	S. by E.	1¾	15° E.	Variation 25° E.
2		6	5				
3		6	4				
4		5	7				
5	S.W. ¾ W.	4	8	S. by E.	3½	7° W.	
6		4	6				
7		4	2				A current set N. by W. ½ W. (correct magnetic), 16 miles from the time the departure was taken to the end of the day.
8		4	4				
9	S. by E.	4	5	E. by S.	2¼	4° E.	
10		4	5				
11		3	6				
12		4	4				

4. 1887, June 1st, in longitude 96° 17′ E., the obs. mer. alt. of the sun's L.L. was 75° 38′ 15″, bearing North, index error + 27″, height of eye 26 feet: required the latitude.

5. In latitude 73° 21′ S. the departure made good was 59·75 miles: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Lat. of A 3° 19′ N. Long. of A 71° 42′ W.
Lat. of B 33 2 S. Long. of B 122 20 W.

7. 1885, June 6th: find the time of high water, A.M. and P.M., at Cardigan, Bridgewater Bar, Jersey, Littlehampton, and Bombay, longitude 73° E.

8. 1887, June 21st, at 9^{h} 16^{m} P.M., apparent time at ship, in latitude 59° 51′ N., longitude 64° 42′ W., sun's bearing by compass N. ¾ E.: required the true amplitude and error of compass; and supposing the variation to be 52° 30′ W.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, June 14th, P.M. at ship, latitude 2° 2′ S., observed altitude sun's L.L. 28° 38′, index correction + 48″, height of eye 12 feet, time by chronometer 14^{d} 13^{h} 3^{m} 18^{s}, which, on April 1st, was 2^{h} 28^{m} $19^{s}\cdot 7$ *fast* for mean noon at Greenwich, and on April 30th was was 2^{h} 24^{m} 19^{s} *fast* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, June 15th, A.M. at ship, latitude 34° 16′ S., longitude 49° 9′ E., sun's bearing by compass E. ¾ N., observed altitude sun's L.L. 12° 43′ 50″, index correction — 1′ 22″, height of eye 26 feet, when a chronometer showed June 14^{d} 17^{h} 6^{m} 54^{s} mean time at Greenwich: required the true azimuth and error of the compass from altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 24° 40′ W.: required the deviation for the position of the ship's head.

11. 1887, June 5th, P.M. at ship, latitude by account 61° 58′ N., longitude 155° 21′ E., the observed altitude of the sun's L.L., South of the observer, was 49° 50′ 30″, index correction + 2′ 10″, height of eye 21 feet, time by chronometer June 4^{d} 14^{h} 20^{m} 8^{s}, which was 6^{m} 0^{s} *fast* on mean time at Greenwich: required the latitude by reduction to meridian.

12. 1887, June 30th, A.M. at ship, and uncertain of my position, when a chronometer showed June 29^{d} 11^{h} 44^{m} 8^{s} M.T.G., observed altitude sun's L.L. 62° 47′ 40″; again, P.M. at ship same day, when chronometer showed June 29^{d} 16^{h} 42^{m} 24^{s}, observed altitude sun's L.L. 30° 3′ 40″, height of eye 21 feet, the ship having made 21 miles on a true N.E. by E. ½ E. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 49° 40′ N. and 50° N.

CHART WORK FOR ONLY AND FIRST MATES.

Outline (True) English Channel Chart. Var. 18° W.

I. Using Deviation Card No. I, find the course to steer by compass from Cape La Heve to Cape Barfleur; also the distance.

II. With the ship's head on the above-named compass course, Cape Barfleur bore by compass S.S.E. ¾ E., also Cape La Hague bore W. ¾ S. by the same compass: find the ship's position.

III. With the ship's head as above Cape de D'Antifer bore by compass N.E., and after continuing the same course 19 miles it bore E. ½ N.: find the ship's position, and the distance from Cape Barfleur at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from Cape La Heve to Cape Barfleur to counteract the effect of a current which set N.W. by W. ½ W. (magnetic) at the rate of 3 miles an hour, the ship making by log 10 miles an hour; also the distance the ship would then make good in 3 hours, and in 1 hour, towards Cape Barfleur.

V. 1885, June 3rd, at 10^{h} 4^{m} P.M., off Cape Barfleur, took a cast of the lead: required the correction to be applied before comparing with soundings.

13. 1887, June 11th, the observed meridian altitude of star Pollux, North of observer, was 48° 40′ 24″, index correction — 1′ 32″, height of eye 20 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 89° W.		South	S. 67° W.	
N.E.	S. 79 W.		S.W.	S. 75 W.	
East	S. 62 W.		West	N. 83 W.	
S.E.	S. 58 W.		N.W.	N. 77 W.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—N.W. by W.; S.W. by W. ½ W.; N.N.E.; S. by W.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—N.W. by N.; W.S.W.; S. ½ W.; S.E. by E. ½ E.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at S.E. by S., find the bearings, correct magnetic.

Compass bearings:—N. ¾ W. and S. 73° W.

Bearings, Magnetic:—

EXAMINATION PAPER—No. VII.

FOR SECOND MATE.

1. Multiply 98400 by 6·5, and 4·7084 by 1267·81, by common logarithms.
2. Divide 242880 by 704, and 680·056 by ·54421, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
1	S.E. by S.	6		S.W. by S.	pts. 1¼	31° W.	A point, lat. 51°25′ N., long. 178° 56′ E., bearing by compass N.E. by N., dist. 17 miles. Ship's head S.E. *b* S. Deviation as per log.
2		5	6				
3		5	4				
4		5					
5	South.	5	5	W.S.W.	2¾	20° W.	
6		5	5				
7		6	5				
8		6	5				
9	West.	6	4	S.S.W.	¾	30° E.	
10		6	6				
11		6	5				
12		6	5				
1	S.S.E.	4	4	S.W.	1½	27½° W.	Variation 28° W.
2		4	4				
3		4	2				
4		4					
5	S.E. by E.	10		S. by W.	½	32½° W.	
6		10	6				
7		9	4				A current set (correct magnetic) N.W. by N., 9 miles, from the time the departure was taken to the end of the day.
8		10					
9	S.S.E.	12	4	East.	¼	20½° W.	
10		12	6				
11		12	6				
12		13	4				

4. 1887, July 26th, in long. 12° 19′ W., the obs. mer. alt. of the sun's L.L. was 15° 41′, bearing North, index error — 3′ 10″, height of eye 19 feet: required the latitude.

5. In latitude 25° 20′ S., the departure made good was 389 miles: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 50° 13′ N. Longitude of A 3° 38′ W.
Latitude of B 37 48 N. Longitude of B 25 10 W.

7. 1885, July 9th: find the time of high water, A.M. and P.M., at Noirmoutier, Port Navalo, Belle Isle, Lynn Deeps, and Madras, long. 80° E.

8. 1887, July 12th, at $5^h\ 9^m$ P.M., apparent time at ship, in latitude 29° 3′ S., longitude 21° 53′ W., sun's bearing by compass W. by N. ¾ N.: required the true amplitude and error of the compass; and supposing the variation to be 11° 20′ W.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, July 17th, P.M. at ship, latitude 31° 32′ S., observed altitude sun's L.L. 13° 23′ 10″, index correction + 5″, height of eye 16 feet, time by chronometer July $16^d\ 22^h\ 3^m\ 49^s$, which, on June 6th, was $9^m\ 17^s$ *fast* for mean noon at Greenwich, and on June 14th was $8^m\ 32^s{\cdot}6$ *fast* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, July 4th, mean time at ship $8^h\ 39^m\ 2^s$ A.M., latitude 38° 10′ S., longitude 78° 35′ W., sun's magnetic azimuth N. 19° 16′ E., observed altitude sun's L.L. 12° 16′ 10″, index error — 2′ 38″, height of eye 14 feet: required the true azimuth and error of the compass; and supposing the variation to be 17° 20′ E.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, July 31st, P.M. at ship, latitude by account 45° 5′ S., longitude 83° 12′ E., observed altitude sun's L.L., North of observer, was 26° 15′ 10″, index error — 40″, height of eye 19 feet, time by watch $30^d\ 23^h\ 50^m$, which had been found to be $36^m\ 16^s$ *slow* on apparent time at ship, the difference of longitude made to the *West* since the error of watch on app. time was determined was 14 miles: required the latitude by reduction to meridian.

12. 1887, July 1st, A.M. at ship, and uncertain of my position, when a chronometer showed June $30^d\ 19^h\ 44^m\ 50^s$ M.T.G., obs. alt. sun's L.L. 30° 2′; again, A.M. at ship same day, when chronometer showed June $30^d\ 22^h\ 2^m\ 52^s$, obs. alt. sun's L.L. 51° 0′ 15″, height of eye 15 feet, the ship having made 25 miles on a true *East* course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 51° 0′ N. and 51° 40′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel Chart (*Magnetic*). Var. 18° W.

I. Using Deviation Card No. I, find the course to steer from Dungeness to Cape de Cayeux, also the distance.

II. With the ship's head on the above-named compass course Dungeness bore by compass N. 13° W., and Varne bore N. 68½° E. by the same compass: find the ship's position.

III. With the ship's head as above Beachy Head bore by compass N. 56° W., and after continuing the same course 25 miles it bore N. 1° E.: find the ship's position and the distance from Beachy Head at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer from Dungeness to Cape de Cayeux to counteract the effect of a current which set East, magnetic, at the rate of 3 miles per hour, the ship making by log 10 miles per hour; also the distance the ship would then make good in 2 hours, and in 1 hour, towards Cape de Cayeux.

V. 1885, July 13th, at $1^h\ 12^m$ A.M., being off Dungeness by reckoning, took a cast of the lead: required the correction to be applied before comparing with soundings.

13. 1887, July 6th, the observed meridian altitude of star α Scorpii (*Antares*), North of observer, was 70° 19′ 50″, index corr. — 9′ 20″, height of eye 21 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation:—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	West.		South	N. 85°W.	
N.E.	S. 72° W.		S.W.	N. 78 W.	
East......	S. 70 W.		West	N. 70 W.	
S.E.......	S. 82 W.		N.W.	N. 73 W.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—E. by N. ¾ N.; S.E. by E. ½ E.; S. by W. ½ W.; N. 1° E.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—W. 1° S.; N. ¼ E.; N.E. by E. ¼ E.; S.E. ½ S.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at N.W. by W., find the bearings, correct magnetic.

Compass bearings:—E. ¼ S., and E. ½ N.

Bearings, magnetic:—

EXAMINATION PAPER—No. VIII.

FOR SECOND MATE.

1. Multiply 777 by 999, and 209·36 by 46, by common logarithms.
2. Divide 111111 by 234, and 1962820 by 10·04, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
1	E.S.E.	14		South.	pts. ¾	28½° W.	A point, lat. 0° 10′ N., long. 179°55′E., bearing by compass W. ¾ N., dist. 23 miles. Ship's head E.S.E. Deviation as per log.
2		13	6				
3		13	4				
4		13					
5	S.E. by E. ½ E.	11	4	S. ½ W.	1¼	22° W.	
6		10	8				
7		11	2				
8		10	6				
9		11					
10	East.	11	2	N.N.E.	1½	25° W.	
11		10	8				
12		11	4				Variation 8° E.
1		11	2				
2		10	4				
3		11					
4	S.E. by E. ¾ E.	10	8	S. ¼ W.	1¼	25° W.	
5		11	2				
6	E. by S. ½ S.	10	6	S. ½ E.	1	25° W.	
7		11	4				A current set E. ¼ N. (correct magnetic) 2¾ miles per hour from the time the departure was taken to the end of the day.
8		10					
9		11					
10	E. ½ N.	10	6	N.N.E.	1¼	24° W.	
11		10	4				
12		11					

4. 1887, August 12th, in longitude 92° 12′ E., the obs. mer. alt. of sun's L.L. was 42° 42′ 10″, bearing North, index error — 2′ 50″, height of eye 17 feet: required the latitude.

5. In latitude 56° 11′ S., the departure made good was 356 miles: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 75° 12′ S. Longitude of A 75° 30′ W.
Latitude of B 70 15 S. Longitude of B 70 27 W.

7. 1885, August 20th: find the time of high water A.M. and P.M. at Ile de Sein, Penzance, Oban, St. Ives, and Cadiz.

8. 1887, August 18th, at $7^h\,22^m$ P.M., apparent time at ship, latitude 57° 29′ S., longitude 104° 50′ E., sun's bearing by compass North: required the true amplitude and error of compass; and supposing the variation to be 37° 40′ W.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, August 7th, P.M. at ship, latitude 6° 4′ N., observed altitude sun's L.L. 24° 5′, index correction + 1′ 30″, height of eye 12 feet, time by chronometer August $6^d\,20^h\,30^m\,36^s$, which, on July 14th, was $36^s{\cdot}2$ *fast* for mean noon at Greenwich, and on July 21st was 10^s *slow* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, August 31st, P.M. at ship, latitude 36° 18′ S., longitude 119° 20′ 15″ W., the sun's bearing by compass N.W. ½ W., observed altitude sun's L.L. 24° 47′ 30″, index correction + 1′ 30″, height of eye 18 feet, when a chronometer showed August $31^d\,11^h\,18^m\,53^s$, mean time at Greenwich: required the true azimuth and error of the compass from the altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 9° 50′ E.: required the deviation for the position of the ship's head.

11. 1887, August 11th, A.M. at ship, latitude by account 39° 3′ S., longitude 157° 25′ E., observed altitude of sun's L.L., North of observer, was 34° 39′ 50″, index correction — 2′ 50″, height of eye 12 feet, time by chronometer August $10^d\,13^h\,5^m\,20^s$, which was $5^m\,10^s$ *fast* on mean time at Greenwich: required the latitude by reduction to meridian.

12. 1887, August 10th, A.M. at ship, and uncertain of my position, when a chronometer showed August $9^d\,21^h\,8^m\,37^s$ M.T.G., observed altitude sun's L.L. 38° 17′; again, P.M. at ship same day, when chronometer showed August $10^d\,3^h\,15^m\,57^s$, observed altitude sun's L.L. 40° 10′ 15″, height of eye 18 feet, the ship having made 21 miles on a true N.E. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 49° 40′ N. and 50° 0′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Outline English Channel Chart (True). Var. 21° W.

I. Using Deviation Card No. I, find the course to steer by compass from Hartland Point to Trevose Head, also the distance.

II. With the ship's head on the above-named compass course Hartland Point bore by compass E. by N., and Lundy Island N.N.E. by the same compass: find the ship's position.

III. With the ship's head as above Hartland Point bore E. by S., and after continuing the same course 10 miles it bore E.N.E.: find the position of the ship and her distance from Hartland Point at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from Hartland Point to Trevose Head (see Question I) to counteract the effect of a current which set S.W. by W. (magnetic) at the rate of 3 miles per hour, the ship making by log 9 miles per hour; also the distance the ship would then make good in 2 hours towards Trevose Head.

V. 1885, August 19th, at $2^h\,35^m$ A.M., off Padstow Island, took a cast of the lead: required the correction of sounding.

13. 1887, August 20th, the obs. mer. alt. of star α Aquilæ (*Altair*), North of observer, was 66° 51′ 10″, index correction + 58″, height of eye 13 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation:—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 14°E.		South	N. 8°W.	
N.E.	N. 13 W.		S.W.	N. 9 E.	
East......	N. 22 W.		West	N. 18 E.	
S.E.......	N. 19 W.		N.W.	N. 21 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—N.W. by W.; S.E. by E. ¾ E.; S. ¼ W.; W. by S. ½ S.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—N.E.; S.W. ½ W.; N. ½ E.; E. ¾ N.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at S. ¾ W., find the bearings, correct magnetic.

Compass bearings:—E. ½ N. and South.

Bearings, magnetic:—

EXAMINATION PAPER—No. IX.

FOR SECOND MATE.

1. Multiply 247·55 by 56·72, and ·03948 by 0·1959, by common logarithms.

2. Divide 69·7565 by 97564, and 33248100 by 830000, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	N.E. ¾ E.	10	3	N. by W. ¼ W.	1¾	35° E.	A point, lat. 60° 9′ N., long. 2° 6′ W., bearing by compass S.W. ¾ S., dist. 22 miles. Ship's head N.E. ¾ E. Deviation as per log.
2		10	8				
3		10	4				
4		10	5				
5	E. by S. ¼ S.	13	5	S. ¾ E.	1½	28° E.	
6		13	4				
7		13	5				
8		13	6				
9	S.W. b W. ¼ W.	9	4	S. ¾ E.	1¾	29° W.	
10		9					
11		9	6				
12		9					
1	North.	8	2	W.N.W.	1¾	12° E.	Variation 24° W.
2		8	4				
3		8	4				
4		8					
5	S.E. ¼ S.	8	4	S.S.W. ¼ W.	2	11° E.	
6		8	6				
7		8	5				A current set (correct magnetic) E. by S. ½ S., 2¾ miles per hour, from the time the departure was taken to the end of the day.
8		8	5				
9	N.E. by E.	10	4	N. by W.	2	34° E.	
10		10	6				
11		10	6				
12		10	4				

4. 1887, September 23rd, in longitude 123° 45′ E., the obs. mer. alt. of the sun's L.L. was 89° 49′ 50″, bearing North, index error — 52″, height of eye 26 feet: required the latitude.

5. In latitude 69° 54′ S., the departure made good was 209·6 miles: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 25° 39′ N. Longitude of A 48° 19′ W.
Latitude of B 34 28 S. Longitude of B 18 28 E.

7. 1885, September 4th, find the time of high water, A.M. and P.M., at Alderney, Heligoland, Nieuport, Fowey, Hastings, and Dornock Road.

8. 1887, September 30th, at $5^h 45^m$ P.M., apparent time at ship, in latitude 52° 30′ N., longitude 12° 10′ W., sun's bearing by compass N.W. ¾ W.: required the true amplitude and error of compass; and supposing the variation to be 30° 28′ W.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, September 1st, P.M. at ship, lat. 9° 9′ N., observed altitude sun's L.L. 62° 13′ 14″, index correction + 15″, height of eye 16 feet, time by chronometer August $31^d 15^h 34^m 28^s$, which, on July 28th, was $2^m 10^s$ *slow* for mean noon at Greenwich, and on August 12th was $1^m 31^s$ *slow* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, September 16th, mean time at ship $8^h 3^m 18^s$ A.M., latitude 4° 22′ N., longitude 81° 39′ W., the sun's bearing by compass N. 93° 20′ E., observed altitude sun's L.L. 29° 30′ 30″, index error + 1′ 22″, height of eye 20 feet: required the true azimuth and error of the compass; and supposing the variation to be 8° 20′ E.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, September 23rd, A.M. at ship, latitude by acct. 27° 32′ S., longitude 168° 51′ E., the observed altitude of the sun's L.L., North of the observer, was 61° 59′ 40″, index correction — 1′ 50″, height of eye 18 feet, time by watch $22^d 23^h 10^m 10^s$, which had been found to be $31^m 31^s$ *slow* on apparent time at ship, the difference of longitude made to the East since the error of watch on apparent time at ship was determined was 24′·4: required the latitude by reduction to meridian.

12. 1887, September 9th, A.M. at ship, and uncertain of my position, when a chronometer showed September $8^d 16^h 23^m 50^s$ M.T.G., observed altitude sun's L.L. 11° 2′ 30″; again, A.M. at ship same day, when chronometer showed September $8^d 20^h 39^m 25^s$, observed altitude sun's L.L. 45° 45′ 30″, height of eye 18 feet, the ship having made 19 miles on a true S. 76° E. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 47° 50′ N., and 47° 10′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Outline English Channel Chart (Magnetic). Var. 21° W.

I. Using Deviation Card No. I, find the course to steer by compass from St. Goven's Head to Hartland Point.

II. With the ship's head on the above-named compass course Lundy Island bore by compass S. ½ E., and Morte Point bore S.E. ½ E. by the same compass: find the ship's position.

III. With the ship's head as above Hartland Point bore by compass S.E. ¾ S., and after continuing on the same course 8 miles it bore S.E. by E.: find the position of the ship, and her distance from Hartland Point at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from St. Goven's Head to Hartland Point (see Question I) to counteract the effect of a current which set West (correct magnetic) at the rate of 2½ miles per hour, the ship making by log 10 miles per hour; also the distance the ship then makes good in 4 hours, and in 1 hour, towards Hartland Point.

V. 1885, September 17th, $3^h 10^m$ P.M. mean time at ship, off Lundy Island, took a cast of the lead: required the correction to be applied before comparing the soundings.

13. 1887, September 7th, the obs. mer. alt. of star Arcturus, North of observer, was 86° 35′ 50″, index correction — 1′ 10″, height of eye 12 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 86° W.		South	N. 88° W.	
N.E.	S. 68 W.		S.W.	N. 80 W.	
East	S. 66 W.		West	N. 72 W.	
S.E.	S. 79 W.		N.W.	N. 75 W.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—W. by S. ¾ S.; N. ½ E.; E. ¾ N.; S.E. ¼ E.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—North; S.S.W. ¼ W.; E. by S. ¼ S.; N.E. ½ E.

Correct magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with ship's head at N.N.E. ¾ E., find the bearings, correct magnetic.

Compass bearings:—N. 79° E. and W. ¼ S.

Bearings, magnetic:—

EXAMINATION PAPER—No. X.

FOR SECOND MATE.

1. Multiply 560072 by 50, and 10·5526 by 317·145, by common logarithms.
2. Divide 8491·9 by 98·4, and 2064840 by 3800·62, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	W.S.W.	11		South.	½	11° W.	A point, lat. 59° 49′ N., long. 43° 54′ W., bearing by compass N. ½ E., dist. 36 miles. Ship's head W.S.W. Deviation as per log.
2		11					
3		10	4				
4		10	6				
5	West.	5		S.S.W.	1	16° W.	
6		5					
7		4	5				
8		4	5				
9	S.E.	13		S.S.W.	½	10° E.	
10		12	2				
11		12	4				
12		12	4				
1	S. by E.	6		S.W. by W.	2¼	4° E.	Variation 70° W.
2		5	5				
3		5					
4		4	5				
5	S.W. by S.	1	5	S.E. by S.	3¼	5° W.	
6		1	5				
7		1	5				A current set the ship S.S.E. (correct magnetic), 48 miles, from the time the departure was taken to the end of the day.
8		1	5				
9	S.W.	6		W.N.W.	1¾	6° W.	
10		5	6				
11		5	4				
12		5					

4. 1887, October 20th, in longitude 150° 25′ W., observed meridian altitude sun's L.L. was 49° 58′ 50″ bearing North, index error + 1′ 10″, height of eye 19 feet: required the latitude.

5. In latitude 59° 36′ N., the departure made good was 52·9 miles: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A	9° 36′ S.	Longitude of A	2° 10′ W.
Latitude of B	7 16 S.	Longitude of B	1 24 W.

7. 1885, October 6th: find the time of high water, A.M. and P.M., at Gibraltar, Ramsgate, Wick, Berwick, and Workington.

8. 1887, October 9th, at $5^h\ 51^m$ A.M., apparent time at ship, in latitude 18° 45′ S., longitude 99° 18′ E., sun's bearing by compass E. ¼ N.: required the true amplitude and error of compass; and supposing the variation to be 1° 50′ W.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, October 30th, P.M. at ship, latitude 32° 45′ N., observed altitude sun's L.L. 28° 30′, index correction + 2′ 30″, height of eye 18 feet, time by chronometer October $30^d\ 11^h\ 56^m\ 43^s$, which, on October 1st, was $2^m\ 28^s$ *slow* for mean noon at Greenwich, and on October 8th was $2^m\ 44^s{\cdot}8$ *slow* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, October 1st, mean time at ship $4^h\ 54^m$ P.M., latitude 17° 8′ S., longitude 152° 33′ W., the sun's magnetic azimuth W. ½ N., observed altitude sun's L.L. 13° 59′, index correction — 22″, height of eye 17 feet: required the true azimuth and error of the compass; and supposing the variation to be 7° 40′ E.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, October 2nd, A.M. at ship, latitude by account 38° 12′ N., longitude 23° 34′ W., observed altitude sun's L.L., South of observer, 47° 30′, index correction — 1′ 38″, height of eye 17 feet, time by watch $2^d\ 1^h\ 50^m$, which had been found to be $2^h\ 10^m$ *fast* on apparent time at ship, the difference of longitude made to the East since the error of watch on apparent time at ship was determined was 43′: required the latitude by reduction to meridian.

12. 1887, October 1st, A.M. at ship, and uncertain of my position, when a chronometer showed October $1^d\ 0^h\ 8^m\ 56^s$ M.T.G., observed altitude sun's L.L. 23° 19′ 50″; again, P.M. at ship same day, when chronometer showed October $1^d\ 5^h\ 53^m\ 52^s$, observed altitude sun's L.L. 25° 30′, height of eye 23 feet, the ship having made 29 miles on a true S.W. ½ S. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 50° 30′ N. and 51° 0′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel (True) Chart. Var. 18° W.

I. Using Deviation Card No. I, find the course to steer by compass from Fecamp to St. Catherine's, also the distance.

II. With the ship's head on the above-named compass course the Owers light bore by compass E. by N. ½ N., and St. Catherine's bore N. by W. ¼ W. by the same compass: find the ship's position.

III. With the ship's head as above, Owers bore by compass N.E. ¼ N., and after continuing the same course 18 miles it bore E. ½ S.: find the ship's position and distance from the Owers at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from Fecamp to St. Catherine's (see Question I) to counteract the effect of a current which set W.S.W., true, at the rate of 2 miles an hour, the ship making by log 32 miles in 4 hours; also the distance the ship would then make good in 4 hours towards St. Catherine's.

V. 1885, October 4th, at $4^h\ 0^m$ A.M., mean time at ship, being off Fecamp, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, October 7th, the observed meridian altitude of star α Pegasi (*Markab*), bearing South, was 54° 19′ 15″, index correction — 9′, height of eye 13 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation:—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 79°W.		South	N. 65°W.	
N.E.	S. 79 W.		S.W.	N. 47 W.	
East......	W. 11 S.		West	N. 39 W.	
S.E.	West.		N.W.	N. 46 W.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—E.N.E.; S.W. ½ W.; S.E. by E. ¾ E.; N. ½ E.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—W.N.W.; S.W. ½ S.; N. ¼ W.; S. ¾ E.

Correct magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at E. ¾ N., find the bearings, correct magnetic.

Compass bearings:—E. ¾ N. and S. ½ E.

Bearings, magnetic:—

EXAMINATION PAPER—No. XI.

FOR SECOND MATE.

1. Multiply 40·405 by 10·8, and ·000586709 by 4827·06, by common logarithms.

2. Divide 100·002 by 1·0012, and 629807 by 3·86098, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	N. by E.	4	2	E. by N.	2¼	3° E.	A point in lat. 52° N., long. 120° E., bearing by compass N. *b* E. ¼ E. dist. 16 miles. Ship's head N. by E. Deviation as per log.
2		3	8				
3		4	5				
4		4	5				
5	N.E. ¾ E.	4	5	N. by W.	3½	17° E.	
6		5					
7		5					
8		4	5				
9	W. ¾ N.	7	5	N. by W.	1¾	17° W.	
10		7	5				
11		8					
12		8					
1	E.S.E.	4	5	South.	3	13° E.	Variation 25° E.
2		4	5				
3		4					
4		4					
5	S.E. ½ S.	4	6	N. by E.	0	9° E.	
6		4	5				
7		4	8				
8		5	1				A current set E.N.E. (correct magnetic), 22 miles from the time the departure was taken to the end of the day.
9	W. ¾ S.	6		N.W. by N.	3¼	14° W.	
10		6	3				
11		6	4				
12		6	3				

4. 1887, November 15th, in longitude 80° 11′ E., the obs. mer. alt. of the sun's L.L. was 67° 44′, bearing North, index error + 1′ 38″, height of eye 15 feet: required the latitude.

5. In latitude 40° 50′ S. the departure made good was 149 miles: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 71° 10′ N.	Longitude of A 76° 4′ E.
Latitude of B 76 0 N.	Longitude of B 80 10 E.

7. 1885, November 1st: find the time of high water, A.M. and P.M., at Ostende, East Looe, Spurn Point, and Ilfracombe.

8. 1887, November 10th, at $4^h\ 3^m\ 52^s$ A.M., apparent time at ship, in latitude 58° 13′ S., longitude 55° 47′ E., sun's bearing by compass S. by E. ½ E.: required the true amplitude and error of compass; and supposing the variation to be 16° 30′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, November 30th, A.M. at ship, latitude 40° 40′ S., observed altitude sun's L.L. 39° 30′, index corr. + 6′ 24″, height of eye 22 feet, time by chronometer Nov. $30^d\ 2^h\ 58^m\ 45^s$, which, on October 13th, was $10^m\ 50^s{\cdot}4$ *fast* for mean noon at Greenwich, and on October 25th was $10^m\ 36^s$ *fast* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, November 15th, mean time at ship $2^h\ 46^m\ 43^s$ P.M., latitude 45° 31′ S., longitude 119° 56′ W., sun's magnetic azimuth S. 98½° W., observed altitude sun's L.L. 43° 45′, index error — 56″, height of eye 20 feet: required the true azimuth and error of the compass; and supposing the variation to be 7° 50′ W.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, November 13th, A.M. at ship, latitude by account 50° 52′ S., longitude 48° 52′ W., the observed altitude of the sun's L.L., North of the observer, was 56°, index error + 23″, height of eye 19 feet, time by watch $13^d\ 0^h\ 4^m\ 34^s$, which had been found to be $43^m\ 24^s$ *fast* on apparent time at ship, the difference of longitude made to the West since the error of watch on apparent time at ship was determined was 9 miles: required the latitude by reduction to meridian.

12. 1887, November 27th, A.M. at ship, and uncertain of my position, when a chronometer showed November $27^d\ 9^h\ 12^m\ 18^s$ M.T.G., observed altitude sun's U.L. 14° 26′ 40″; again, P.M. at ship same day, when chronometer showed November $27^d\ 13^h\ 32^m\ 19^s$ M.T.G., observed altitude sun's U.L. 18° 46′ 40″, height of eye 27 feet, the ship having made 30 miles on a true W. by S. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 46° 0′ N. and 46° 40′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel Chart (True). Var. 18° W.

I. Using Deviation Card No. I, find the course to steer by compass from Cape de la Heve to Nab lightvessel, also the distance.

II. With the ship's head on the above-named compass course the Owers light bore by compass E. ¾ S., and the Nab lightvessel N. ¾ E.: find the ship's position.

III. With the ship's head as above the Owers light bore by compass E. by N. ¾ N., and after continuing on the same course 10 miles it bore S.E. ¾ E.: find the position of the ship, and her distance from the Owers light at the time of taking the second observation.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from Cape de la Heve to the Nab Lightvessel (see Question I) to counteract the effect of a current which set W. by S. (true) at the rate of 1½ miles per hour, the ship making by log 13½ miles in 3 hours; also the distance the ship would then make good in 3 hours towards the Nab Lightvessel.

V. 1885, November 8th, at $10^h\ 12^m$ A.M. mean time at ship, off Bembridge Point, took a cast of the lead: required the correction to be applied to the soundings.

13. 1887, November 7th, the obs. mer. alt. of star α Piscis Australis (*Fomalhaut*) bearing North, was 59° 40′, index correction + 1′ 12″, height of eye 23 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 88° W.		South	N. 88° W.	
N.E.	S. 70 W.		S.W.	N. 80 W.	
East......	S. 68 W.		West	N. 72 W.	
S.E.......	S. 80 W.		N.W.	N. 75 W.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct Magnetic courses:—W. by S. ¼ S.; N.W. by W. ½ W.; E. by S. ½ S.; S. ¼ E.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—W. ½ N.; N. 42° W.; S. 64° E.; N.E. ½ N.

Correct magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at W. by N. ½ N., find the bearings, correct magnetic.

Compass bearings:—W. ½ N. and S. 36° E.

Bearings, magnetic:—

EXAMINATION PAPER—No. XII.

FOR SECOND MATE.

1. Multiply 758900 by 13·5, and 0·006994 by 0·33318, by common logarithms.
2. Divide 999·43 by 67·832, and 1875000 by 15000, by common logarithms.
3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	E. by N. ¼ N.	3	5	N. ½ E.	2	11° E.	A point, lat. 50° N., long. 40° W., bearing by compass E.N.E. ½ E. dist. 16 miles. Ship's head E. by N. ¼ N. Deviation as per log.
2		3	3				
3		4					
4		4	2				
5	W.N.W.	6	5	North.	1½	10° W.	
6		6	2				
7		5	6				
8		4	7				
9	S.S.W. ½ W.	4	2	West.	2½	4° W.	
10		4					
11		3	6				
12		3	2				
1	N.N.W. ¼ W.	5	6	West.	1¾	5° W.	Variation 36½° W.
2		5	6				
3		6	4				
4		6	4				
5	S.E. ¾ E.	6	2	S.S.W.	1½	7° E.	
6		5	6				
7		5	2				
8		5					A current set S.S.W. (correct magnetic), 6 miles from the time the departure was taken to the end of the day.
9	S.W. ¾ W.	2	5	S. by E. ½ E.	3¾	6° W.	
10		3	2				
11		3					
12		3	3				

4. 1887, December 31st, in longitude 123° 45′ W., the obs. mer. alt. of the sun's L.L. was 67° 8′ 10″, bearing South, index error + 9″, height of eye 13 feet: required the latitude.

5. In latitude 60° N. the departure made good was 111 miles East: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from Port San Francisco to Cape Palliser, by calculation on Mercator's principle.

Lat. of San Francisco	37°48′ N.	Long. of San Francisco	122°24′ W.
Lat. of Cape Palliser	41 38 S.	Long. of Cape Palliser	175 21 E.

7. 1885, December 2nd: find the time of high water, A.M. and P.M., at Skull, Westport, Valentia, Limerick, Coleraine, and Tenby.

8. 1887, December 28th, at $4^h\ 11^m\ 13^s$ A.M., apparent time at ship, in latitude 46° 47′ S., longitude 179° 54′ W., sun's bearing by compass S.E. by E. ¾ E.: required the true amplitude and error of compass; and supposing the variation to be 15° 30′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, December 25th, P.M. at ship, latitude 33° 33′ S., observed altitude sun's L.L. 40° 40′ 40″, index correction + 2′ 20″, height of eye 19 feet, time by chronometer December $24^d\ 15^h\ 37^m\ 17^s$, which, on October 31st, was $6^m\ 8^s$ *slow* for mean noon at Greenwich, and on November 12th was $7^m\ 16^s{\cdot}4$ *slow* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, December 27th, mean time at ship $8^h\ 0^m\ 10^s$ A.M., latitude 15° 12′ N., longitude 130° W., sun's magnetic azimuth E. by S. ¾ S., observed altitude sun's L.L. 20° 15′, index correction + 2′ 5″, height of eye 16 feet: required the true azimuth and error of the compass; and supposing the variation to be 7° 20′ E.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, December 4th, A.M. at ship, latitude by account 51° 54′ S., longitude 30° 10′ W., the observed altitude of the sun's L.L., North of the observer, was 59° 59′, index correction — 3′ 12″, height of eye 20 feet, time by watch $12^m\ 10^s$ (or $4^d\ 0^h\ 12^m\ 10^s$), which had been found to be $42^m\ 10^s$ *fast* on apparent time at ship, the difference of longitude made to the West since the error of watch on apparent time at ship was determined was 10 miles: required the latitude by reduction to meridian.

12. 1887, December 25th, A.M. at ship, and uncertain of my position, when a chronometer showed December $24^d\ 22^h\ 11^m\ 2^s$ M.T.G., observed altitude sun's L.L. 9° 8′; again, P.M. at ship same day, when chronometer showed December $25^d\ 3^h\ 15^m$ M.T.G., observed altitude sun's L.L. 15° 3′, height of eye 15 feet, the ship having made 35 miles on a true S. 54° E. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 46° 30′ N. and 46° 0′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel (*True*) *Chart*. Var. 18° W.

I. Using Deviation Card No. I, find the course to steer by compass from A to St. Catherine's Light; also the distance.

A, Latitude 50° 35′ N. Longitude 0° 37′ E.

II. With the ship's head on the above-named compass course, Beachy Head bore by compass W. ¼ N., and Dungeness bore N.N.E. ¾ E. by the same compass: find the ship's position.

III. With the ship's head as above Beachy Head bore by compass N. ½ W., and after continuing the same course 13 miles it bore E. by N. ½ N.: find the ship's position, and distance from Beachy Head at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from A to St. Catherine's (see Question I) to counteract the effect of a current which set East (true) at the rate of 5 miles an hour, the ship making by log 32 miles in 3 hours; also the distance the ship would then make good per hour towards St. Catherine's.

V. 1885, December 7th, at $2^h\ 56^m$ P.M. mean time at ship, off Selsea Bill by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, December 21st, the obs. mer. alt. of star α Canis Minoris (*Procyon*) was 52° 51′ 50″, bearing North, index corr. — 49″, height of eye 21 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 2° W.		South	S. 5° E.	
N.E.	S. 4 W.		S.W.	S. 24 E.	
East	S. 10 W.		West	S. 16 E.	
S.E.	S. 16 W.		N.W.	S. 3 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—N. 78° E.; E.S.E.; S.W. by W. ½ W.; N. ¾ W.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—S.S.E.; W. by S. ½ S.; S. by W. ½ W.; S.E. ½ S.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at S.W. by S., find the bearings, correct magnetic.

Compass bearings:—W. by S. ½ S. and N.N.W.

Bearings, Magnetic:—

EXAMINATION PAPER—No. XIII.

FOR SECOND MATE.

1. **Multiply 198400 by 6·5, and 448000 by ·0000448, by common logarithms.**
2. **Divide 2208000 by 3450, and ·085375 by ·07425, by common logarithms.**

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	S.S.W. ¼ W.	12	2	West.	¼	42° W.	A point, lat. 62° 18′ N., long. 83° 17′ E., bearing by compass N. by E. ½ E., dist. 23 miles. Ship's head S.S.W. ¼ W. Deviation as per log.
2		12	6				
3		13	2				
4		13					
5	S.W. ¾ W.	11	5	S. by E.	½	8° W.	
6		11	4				
7		11	1				
8		11					
9	E. ¾ S.	5	4	S. by E.	1¾	15° E.	
10		5	6				
11		5	6				
12		5	4				
1	W.N.W.	4	4	North.	3	19° W.	Variation 42° E.
2		4	4				
3		4	2				
4		5					
5	N.W. ½ N.	10	6	S. by W.	0	16½° W.	
6		10	2				
7		11	4				A current set (correct magnetic) S.W. ¼ W., 52 miles, from the time the departure was taken to the end of the day.
8		11	8				
9	E. ¾ N.	3	2	N. by E.	3¼	17¼° E.	
10		3	2				
11		3	2				
12		2	4				

4. 1887, August 11th, in long. 92° 12′ E., the obs. mer. alt. of the sun's L.L. was 42° 42′ 10″, bearing North, index error — 2′ 50″, height of eye 17 feet: required the latitude.

5. In latitude 80° the departure made good was 80 miles: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A	49° 20′ S.	Longitude of A	22° 13′ E.
Latitude of B	Equator.	Longitude of B	Meridian of Greenwich.

7. 1885, September 1st: find the time of high water, A.M. and P.M., at Barfleur, Portland Breakwater, Bardsey Island, and Padstow.

8. 1887, October 28th, at $8^h\,30^m$ A.M., apparent time at ship, in latitude 49° 40′ N., longitude 116° 12′ W., sun's bearing by compass E. 10° 40′ N.: required the true amplitude and error of the compass; and supposing the variation to be 23° 50′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, April 18th, A.M. at ship, latitude 50° 48′ N., observed altitude sun's L.L. 38° 10′ 50″, index correction + 45″, height of eye 16 feet, time by chronometer $9^h\,27^m\,2^s$ A.M., which, on March 17th, was $0^m\,49^s{\cdot}3$ *slow* for mean noon at Greenwich, and on April 1st was $1^m\,58^s{\cdot}7$ *fast* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, September 1st, P.M. at ship, latitude 35° 49′ N., longitude 111° 28′ 30″ E., sun's magnetic azimuth S.W. by W. ¾ W., observed altitude sun's L.L. 44° 32′ 10″, index error + 1′ 46″, height of eye 20 feet, when a chronometer showed August $31^d\,19^h\,12^m\,18^s$ M.T.G.: required the true azimuth and error of the compass; and supposing the variation to be 1° 15′ E.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, July 28th, A.M. at ship, latitude by account 38° 54′ N., longitude 39° W., observed altitude sun's L.L., South of observer, was 69° 10′, index error + 1′ 27″, height of eye 23 feet, time by watch $27^d\,23^h\,3^m\,15^s$, which had been found to be $28^m\,45^s$ *slow* on apparent time at ship, the difference of longitude made to the East since the error of watch on apparent time at ship was determined was 32 miles: required the latitude by reduction to meridian.

12. 1887, February 28th, A.M. at ship, and uncertain of my position, when a chronometer showed February $28^d\,9^h\,4^m\,12^s$ M.T.G., obs. alt. sun's L.L. 27° 31′; again, P.M. at ship same day, when chronometer showed February $28^d\,12^h\,25^m\,35^s$, obs. alt. sun's L.L. 32° 40′, height of eye 20 feet, the ship having made 27 miles on a true N.E. ¼ E. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 47° 10′ N. and 47° 40′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel Chart (*True*). Var. 17° W.

I. Using Deviation Card No. II, find the course to steer by compass from Cape Alprech to Beachy Head, also the distance.

II. With the ship's head on the above-named compass course the Varne light bore by compass E. ¾ N., and Dungeness bore N.E. ¼ N. by the same compass: find the ship's position.

III. With the ship's head as above Dungeness bore by compass N. ½ E., and after continuing the same course 16 miles it bore E. by N. ½ N.: find the ship's position and the distance from Dungeness at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from Cape Alprech to Beachy Head (see Question I) to counteract the effect of a current which set S.W. ¾ W. (true), at the rate of 3 miles an hour, the ship making by log 54 miles in 6 hours; also the distance the ship would then make good in 6 hours towards Beachy Head.

V. 1885, September 26th, at $11^h\,56^m$ A.M., mean time at ship, being off Beachy Head by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, October 8th, the observed meridian altitude of star α Gruis, South of observer, was 50°, index corr. — 1′ 12″, height of eye 17 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation:—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	East.		South	S. 87°E.	
N.E.	S. 67° E.		S.W.	N. 63 E.	
East......	S. 60 E.		West	N. 60 E.	
S.E.......	S. 68 E.		N.W.	N. 69 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—S.W. by S.; N. by E. ¾ E.; North; E. ½ N.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—W. by S.; N.W. ½ N.; S. ½ W.; S. by E. ¾ E.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at E. ½ S., find the bearings, correct magnetic.

Compass bearings:—E. ½ S., and W. by S.

Bearings, magnetic:—

EXAMINATION PAPER—No. XIV.

FOR SECOND MATE.

1. Multiply 173·4 by 1·734, and 60030041 by ·000273004, by common logarithms.

2. Divide 763987·4 by 9·46703, and 471 by 964325, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	E. ¼ S.	10	4	S. by E. ½ E.	¼	27½° W.	A point, lat. 30° 16′N., long. 179°52′E., bearing by compass N. b E. ¼ E., dist. 15 miles. Ship's head E. ¼ S. Deviation as per log.
2		10	6				
3		10	6				
4		10	4				
5	E. by S. ¼ S.	8	6	S. by E.	1¾	34½° W.	
6		8	4				
7		7	8				
8		7	2				
9	W. by S. ½ S.	9	6	South.	2½	7° E.	
10		9	4				
11		9	5				
12		8	5				
1	S. ¾ W.	9	3	S.E. by E.	1¼	46° W.	Variation 12° 30′ E.
2		9	4				
3		9	3				
4		9					
5	N. ¼ W.	9	5	E.N.E.	¾	50° E.	
6		9	5				
7		9	6				
8		9	4				A current set N. ¼ W. (correct magnetic) 17½ miles from the time the departure was taken to the end of the day.
9	E. ½ S.	8	4	S.S.E.	2½	28° W.	
10		7	6				
11		6	4				
12		5	6				

4. 1887, March 20th, in longitude 174° W., the obs. mer. alt. of sun's L.L. was 89° 56′ 10″, bearing North, index error — 1′ 15″, height of eye 15 feet: required the latitude.

5. In latitude 71° 44′ N., the departure made good was 164 miles: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.
Latitude of A 2° 49′ N. Longitude of A 130° 9′ E.
Latitude of B 0 20 S. Longitude of B 82 16 W.

7. 1885, June 20th: find the time of high water, A.M. and P.M., at Lyme Regis, Hurst Camber, St. Malo, Ilfracombe, Padstow, and Fowey.

8. 1887, December 6th, at 0^h 16^m A.M., apparent time at ship, latitude 67° 19′ S., longitude 19° 2′ E., sun's bearing by compass S. ¾ W.: required the true amplitude and error of compass; and supposing the variation to be 24° 50′ W.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, September 1st, A.M. at ship, latitude 47° 48′ N., observed altitude sun's L.L. 39° 46′ 50″, index correction + 2′ 10″, height of eye 13 feet, time by chronometer August 31^d 10^h 17^m 20^s, which, on June 30th, was 8^m 20^s *slow* for mean noon at Greenwich, and *losing* $3^s.5$ daily: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, March 20th, A.M. at ship, latitude 43° 18′ N., longitude 31° 41′ W., the sun's bearing by compass S. ¼ E., observed altitude sun's L.L. 35° 2′ 50″, index correction 0, height of eye 12 feet, when a chronometer showed March 19^d 23^h 44^m 40^s, mean time at Greenwich: required the true azimuth and error of the compass from the altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 27° 10′ W.: required the deviation for the position of the ship's head.

11. 1887, September 23rd, A.M. at ship, latitude by account 28° 5′ S., long. 170° 57′ E., observed altitude of sun's L.L., North of observer, was 61° 49′ 20″, index correction — 9′ 20″, height of eye 19 feet, time by chronometer September 22^d 12^h 15^m, which was 4^m 5^s *slow* on mean time at Greenwich: required the latitude by reduction to meridian.

12. 1887, September 26th, A.M. at ship, and uncertain of my position, when a chronometer showed September 25^d 7^h 3^m 36^s M.T.G., observed altitude sun's L.L. 10° 53′ 15″; again, P.M. at ship same day, when chronometer showed September 25^d 15^h 0^m 10^s, observed altitude sun's L.L. 26° 48′ 10″, height of eye 15 feet, the ship having made 33 miles on a true E.S.E. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 47° 10′ N. and 46° 40′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Outline English Channel Chart (True). Var. 21° W.

I. Using Deviation Card No. I, find the course to steer by compass from A to Lizard Light, also the distance.

A, Latitude 49° 32′ N. Longitude 7° 0′ W.

II. With the ship's head on the above-named compass course Longships bore by compass E. ½ N., and St. Agnes' bore N.W. by W. by the same compass: find the ship's position

III. With the ship's head as above Wolf Rock bore by compass N.E. ½ E., and after continuing on the same course 15 miles it bore N.W. ½ N.: find the position of the ship, and her distance from Wolf Rock at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from A to Lizard (see Question I) to counteract the effect of a current which set E.N.E. (magnetic) at the rate of 4 miles per hour, the ship making by log 57 miles in 6 hours; also the distance the ship would then make good in 6 hours towards Lizard.

V. 1885, July 7th, at 3^h 5^m P.M., being off St. Mary's, Scilly Islands, by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, December 21st, the obs. mer. alt. of star α Cygni (*Deneb*), North of observer, was 56° 18′ 50″, index correction — 40″, height of eye 15 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation:—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 77°W.		South	S. 61°W.	
N.E.	N. 88 W.		S.W.	S. 59 W.	
East......	S. 85 W.		West	S. 77 W.	
S.E.......	S. 78 W.		N.W.	N. 81 W.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—N.E. by E.; S.W. by S.; E.S.E.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—W. ½ S.; N.W. by N.; N.E. by N.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at N.W., find the bearings, correct magnetic.

Compass bearings:—North and E.S.E.

Bearings, magnetic:—

EXAMINATION PAPER—No. XV.

FOR SECOND MATE.

1. Multiply 100001 by 8, and 160800 by 325, by common logarithms.
2. Divide 37·149 by 523·76, and 615 by ·03075, by common logarithms.
3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way. pts.	Deviation.	Remarks, &c.
1	S. by E. ½ E.	3	3	S.W. ½ W.	2½	5° E.	A point, Cape of Good Hope, in lat. 34° 28′ S., long. 18° 28′ E., bearing by compass N. by W. ¾ W., dist. 21 miles. Ship's head S. by E. ½ E. Deviation as per log.
2		3	4				
3		3	6				
4		3	7				
5	N.W. ½ W.	2	4	S.W. by W.	3½	18° W.	
6		2	3				
7		2	3				
8		2					
9	N. by E. ½ E.	4	6	N.W. ½ W.	2¼	6° E.	
10		4	4				
11		4	7				
12		4	3				
1	S.W. *b* W. ½ W.	5	6	N.W. ½ W.	1¾	7° W.	
2		5	7				Variation 25° W.
3		5	4				
4		5	3				
5	W. by N. ½ N.	7	5	N. ½ W.	½	16° W.	
6		7	6				
7		7	2				
8		6	7				A current set (correct magnetic) E. by S. ¼ S., 14 miles, from the time the departure was taken to the end of the day.
9	N.E. ¼ E.	5	3	E.S.E.	2	16° E.	
10		4	4				
11		5	5				
12		5	4				

4. 1887, February 11th, in longitude 32° 20′ E., the obs. mer. alt. of the sun's L.L. was 30° 25′ 10″, bearing South, index error — 3′ 15″, height of eye 22 feet: required the latitude.

5. In latitude 84° 49′, the departure made good was 89·75 miles: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 43° 24′ S. Longitude of A 65° 39′ W.
Latitude of B 26 38 N. Longitude of B 15 8 E.

7. 1885, April 3rd: find the time of high water, A.M. and P.M., at Aberdovey, Port Patrick, Arklow, Ballycastle Bay, and Ardrossan.

8. 1887, March 31st, at $6^h\ 1^m\ 48^s$ A.M., apparent time at ship, in latitude 6° 31′ N., longitude 155° 10′ E., sun's bearing by compass E. 3° 51′ S.: required the true amplitude and error of compass; and supposing the variation to be 6° E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, May 27th, A.M. at ship, lat. 55° N., observed altitude sun's L.L. 43° 9′ 5″, index correction — 14″, height of eye 14 feet, time by chronometer $9^h\ 13^m\ 12^s$ A.M. (or $26^d\ 21^h\ 13^m\ 12^s$), which, on April 24th, was 25^s *fast* for mean noon at Greenwich, and *gaining* $4^s{\cdot}9$ daily: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, July 10th, A.M. at ship, latitude 59° 56′ N., longitude 40° 20′ W., the sun's bearing by compass S. ½ W., observed altitude sun's L.L. 44° 49′ 50″, index correction — 50″, height of eye 21 feet, when a chronometer showed $10^d\ 0^h\ 25^m\ 20^s$, mean time at Greenwich: required the true azimuth and error of the compass from altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 51° W.: required the deviation for the position of the ship's head.

11. 1887, June 14th, A.M. at ship, latitude by account 57° 43′ N., longitude 10° 14′ W., the observed altitude of the sun's L.L., South of the observer, was 55° 24′ 15″, index correction — 6′ 12″, height of eye 19 feet, time by chronometer $14^d\ 0^h\ 40^m\ 12^s$, which was $13^m\ 43^s$ *fast* on mean time at Greenwich: required the latitude by reduction to meridian.

12. 1887, January 17th, A.M. at ship, and uncertain of my position, when a chronometer showed January $16^d\ 17^h\ 46^m\ 14^s$ M.T.G., observed altitude sun's L.L. 13° 10′ 0″; again, P.M. at ship same day, when chronometer showed January $16^d\ 23^h\ 55^m\ 1^s$, observed altitude sun's L.L. 8° 47′ 0″, height of eye 18 feet, the ship having made 30 miles on a true N.W. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 46° 0′ N., and 46° 30′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Outline English Channel Chart (True). Var. 21° W.

I. Using Deviation Card No. I, find the course to steer by compass from A to Lundy Island, also the distance.

A, Latitude 50° 39′ N. Longitude 5° 34′ W.

II. With the ship's head on the above-named compass course Longships light bore by compass S.S.E. ½ E., and Seven Stones bore W. by S. ½ S. by the same compass: find the ship's position.

III. With the ship's head as above Trevose Head bore by compass S.E. ½ E., and after continuing on the same course 14 miles it bore S. ½ E.: find the position of the ship, and her distance from Trevose Head at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from A to Lundy Island (see Question I) to counteract the effect of a current which set N.N.E. (true) at the rate of 5 miles per hour, the ship making by log 36 miles in 3 hours; also the distance the ship would then make good in 3 hours towards Lundy Island.

V. 1885, November 30th, $9^h\ 30^m$ P.M., being off St. Ives by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, July 19th, the obs. mer. alt. of star α Pavonis, bearing South, was 32° 50′ 15″, index correction + 4′ 48″, height of eye 23 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 44°E.		South	S. 11°W.	
N.E.	S. 56 E.		S.W.	S. 13 W.	
East	S. 39 E.		West	S. 4 W.	
S.E.	S. 12 E.		N.W.	S. 12 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—N.N.W.; W.N.W.; S.W. by W.; W.S.W.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—E.N.E.; S.S.E.; N.W. by W.; N.E. by E.

Correct magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with ship's head at N.E. ½ E., find the bearings, correct magnetic.

Compass bearings:—N. by W. and E. by N.

Bearings, magnetic:—

EXAMINATION PAPER—No. XVI.

FOR SECOND MATE.

1. Multiply 108·581 by 500, and 964·3204 by ·000690041, by common logarithms.
2. Divide 408848 by 202, and ·000694321 by ·000014798, by common logarithms.
3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	W. by N. ¼ N.	8	9	N. by W.	2½	21° 10′ W.	A point, lat. 59° 16′ S., long. 179° 42′ W., bearing by compass S.E. ½ E., dist. 13 miles. Ship's head W. by N. ¼ N. Deviation as per log.
2		8	3				
3		8	4				
4		8	4				
5	W. ¾ N.	9	4	N. by W.	2¼	19° 50′ W.	
6		9	8				
7		8	6				
8		8	4				
9	W. ¼ N.	9	8	N. by W.	2¾	18° 15′ W.	
10		9	7				
11		9	6				
12		9	5				
1	S.S.W. ½ W.	8	8	W. ½ N.	3¼	4° 30′ W.	Variation 15° 40′ E.
2		8	2				
3		8	5				
4		8	6				
5	S.S.E. ¼ E.	3	6	S.W.	¾	27° 40′ E.	
6		3	2				
7		4	8				A current set the ship S. ½ E. (correct magnetic), 21 miles, from the time the departure was taken to the end of the day.
8		5	6				
9	W. ¾ S.	8	6	South.	2¼	19° 30′ W.	
10		8	2				
11		8	3				
12		8	4				

4. 1887, May 16th, in longitude 45° 26′ W., observed meridian altitude sun's L.L. was 86° 34′ 20″ bearing North, index error + 4′ 16″, height of eye 15 feet: required the latitude.

5. In latitude 76°, the departure made good was 76 miles: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A	9° 2′ N.	Longitude of A	171° 19′ W.
Latitude of B	1 2 S.	Longitude of B	83 17 E.

7. 1885, September 5th: find the time of high water A.M. and P.M., at Ile d'Aix, Abervrach, Rotterdam, Porth-dyn-lleyn, Port Carlisle, and Workington.

8. 1887, June 24th, at 11^h 5^m P.M., apparent time at ship, in latitude 66° 31′ N., longitude 9° W., sun's bearing by compass N. ¾ E.: required the true amplitude and error of compass; and supposing the variation to be 33° 30′ W.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, June 15th, A.M. at ship, latitude 29° 10′ S., observed altitude sun's L.L. 20° 40′ 0″, index correction 0, height of eye 25 feet, time by chronometer June 14^d 22^h 59^m 20^s, which, on May 3rd, was 1^m 17^s *slow* for mean noon at Greenwich, and *losing* 8^s daily: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, September 23rd, P.M. at ship, latitude 49° 40′ S., longitude 115° 34′ 30″ W., the sun's bearing by compass N. by E. ¼ E., observed altitude sun's L.L. 30° 17′ 50″, index correction 0, height of eye 14 feet, when a chronometer showed September 23^d 10^h 9^m 47^s mean time at Greenwich: required the true azimuth and error of the compass from altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 28° 50′ W.: required the deviation for the position of the ship's head.

11. 1887, September 23rd, P.M. at ship, latitude by account 50° 57′ N., longitude 169° 54′ E., observed altitude sun's L.L., South of observer, was 38° 47′, index correction 0″, height of eye 12 feet, time by chronometer September 22^d 12^h 59^m 45^s, which was 7^m 31^s *fast* on mean time at Greenwich: required the latitude by reduction to meridian.

12. 1887, August 18th, A.M. at ship, and uncertain of my position, when a chronometer showed August 17^d 20^h 10^m 48^s M.T.G., observed altitude sun's L.L. 17° 32′ 0″; again, A.M. at ship same day, when chronometer showed August 17^d 22^h 52^m 27^s, observed altitude sun's L.L. 41° 45′ 26″, height of eye 20 feet, the ship having made 19½ miles on a true W.N.W. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 49° 25′ N. and 49° 55′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel (Magnetic) Chart. Var. 19° W.

I. Using Deviation Card No. I, find the course to steer by compass from A to Bill of Portland, also the distance.

A,	Latitude 49° 56′ N.	Longitude 4° 27′ W.

II. With the ship's head on the above-named compass course Eddystone bore by compass N.N.W. ¼ W., and Start Point bore E. ¾ N. by the same compass: find the ship's position.

III. With the ship's head as above, Start Point bore by compass N. by E. ½ E., and after continuing on the same course 8 miles it bore N.W. ¼ W.: find the position of the ship and her distance from Start Point at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from A to Bill of Portland (see Question I) to counteract the effect of a current which set E. by S., true, at the rate of 4 miles per hour, the ship making by log 24 miles in 3 hours, also the distance the ship would then make good in 3 hours towards Bill of Portland.

V. 1885, June 7th, at 9^h 40^m A.M., being off Exmouth by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, March 31st, the observed meridian altitude of star α Virginis (*Spica*), North of observer, was 52° 14′ 0″, index correction 0, height of eye 19 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation :—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 35°W.		South	S. 10°E.	
N.E.	S. 13 W.		S.W.	S. 11 E.	
East......	S. 6 W.		West	S. 14 W.	
S.E.	S. 3 W.		N.W.	S. 37 W.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses :—East ; W.S.W.; S.E. by S.

Compass courses :—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses :—N.W. by W. ½ W.; North; E.N.E.

Correct magnetic courses :—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at W.S.W., find the bearings, correct magnetic.

Compass bearings :—W. by S. and South.

Bearings, magnetic :—

EXAMINATION PAPER—No. XVII.

FOR SECOND MATE.

1. Multiply 37340 by 1200, and 53·62 by 0·4188, by common logarithms.
2. Divide 9145752 by 22·22, and 5·6949 by 53·058, by common logarithms,

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	E.N.E.	10	8	North.	1½	25° E.	A point, lat. 37° 37′ N., long. 0° 41′ W., bearing by compass W. ½ N., dist. 20 miles. Ship's head E.N.E. Deviation as per log.
2		11					
3		10	2				
4		11					
5	E. ¾ S.	10	8	S. by E. ¾ E.	1½	23° E.	
6		11					
7		11	2				
8		11					
9	East.	12		S.S.E.	1¼	24° E.	
10		12					
11		12					
12		12					
1	E. by S. ¾ S.	11		S. ¼ E.	1¾	20° E.	Variation 19° W.
2		10	2				
3		11					
4		10	8				
5	N.E. by E. ¾ E.	11	3	N. ¼ W.	1½	24° E.	
6		10					
7		10	2				A current set E.N.E. (correct magnetic), 3¼ miles per hour, from the time the departure was taken to the end of the day.
8		10	5				
9	N.E. ¾ N.	11		N.N.W. ¾ W.	1¾	21° E.	
10		11	5				
11		10	8				
12		10	7				

4. 1887, November 21st, in longitude 70° 20′ E., the obs. mer. alt. of the sun's U.L. was 80° 52′ 30″, bearing North, index error — 2′ 52″, height of eye 20 feet: required the latitude.

5. In latitude 44° 50′ N., the departure made good was 379·75 miles: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from (A) Hong Kong to (B) Callao, by calculation on Mercator's principle.

Latitude of A 22° 17′ N.	Longitude of A 114° 30′ E.
Latitude of B 12 4 S.	Longitude of B 77 14 W.

7. 1885, February 1st: find the time of high water, A.M. and P.M., at Orfordness, Loch Ryan, Peel, Warren Point, and Ostende.

8. 1887. June 30th, at $2^{h}\ 43^{m}$ A.M., apparent time at ship, in latitude 60° 48′ N., longitude 177° 23′ 30″ E., sun's bearing by compass N. by W. ½ W.: required the true amplitude and error of compass; and supposing the variation to be 20° 10′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, June 5th, A.M. at ship, latitude 2° 5′ S., observed altitude sun's L.L. 28° 4′, index corr. + 4′ 25″, height of eye 15 feet, time by chronometer June $4^{d}\ 12^{h}\ 28^{m}\ 42^{s}$, which, on March 6th, was $1^{m}\ 6^{s}$ *fast* for mean noon at Greenwich, and on May 1st showed mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, September 29th, mean time at ship $1^{h}\ 41^{m}\ 35^{s}$ P.M., latitude 53° 27′ N., longitude 171° 39′ 30″ E., sun's bearing by compass S. ½ E., observed altitude sun's L.L. 29° 17′ 10″, index error + 4′ 10″, height of eye 35 feet: required the true azimuth and error of the compass; and supposing the variation to be 15° 15′ E.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, May 30th, A.M. at ship, latitude by account 71° 32′ N., longitude 9° 49′ 10″ W., the observed altitude of the sun's L.L., South of the observer, was 39° 50′, index error + 4′ 25″, height of eye 31 feet, time by watch May $30^{d}\ 0^{h}\ 43^{m}\ 29^{s}$, which had been found to be $1^{h}\ 2^{m}\ 50^{s}$ *fast* on apparent time at ship, the difference of longitude made to the East since the error of watch on apparent time at ship was determined was 17½ miles: required the latitude by reduction to meridian.

12. 1887, July 2nd, A.M. at ship, and uncertain of my position, when a chronometer showed $1^{d}\ 20^{h}\ 2^{m}\ 3^{s}$ M.T.G., observed altitude sun's L.L. 31° 9′ 21″; again, A.M. at ship same day, when chronometer showed $1^{d}\ 22^{h}\ 18^{m}\ 29^{s}$ M.T.G., observed altitude sun's L.L. 52° 50′ 14″, height of eye 18 feet, the ship having made 15 miles on a true N.N.W. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 48° 0′ N. and 48° 20′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel Chart (Magnetic). Var. 19½° W.

I. Using Deviation Card No. I, find the course to steer by compass from A to Hanois light, also the distance.

A, Latitude 48° 55′ N. Longitude 4° 20′ W.

II. With the ship's head on the above-named compass course Isle de Bas bore by compass S.W. ¾ S., and Triagoz bore S. by E. ½ E. by the same compass: find the ship's position.

III. With the ship's head as above Isle de Bas bore by compass S.E. ¾ S., and after continuing on the same course 14½ miles it bore S. by W. ¾ W.: find the position of the ship, and her distance from Isle de Bas at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from A to Guernsey (see Question I) to counteract the effect of a current which set N.E. (magnetic) at the rate of 5 miles per hour, the ship making by log 30 miles in 3 hours; also the distance the ship would then make good in 3 hours towards Guernsey.

V. 1885, October 4th, at $10^{h}\ 42^{m}$ P.M., being off Port St. Peter, Guernsey, by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, February 1st, long. 50° W., obs. mer. alt. of star α Canis Majoris (*Sirius*), South of observer, was 37° 50′ 20″, index corr. + 1′ 4″, height of eye 30 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	North.		South	N. 24°E.	
N.E.	N. 12°E.		S.W.	N. 5 E.	
East......	N. 29 E.		West	N. 5 W.	
S.E.......	N. 36 E.		N.W.	N. 5 W.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct Magnetic courses:—W.N.W.; W.S.W.; S.E. by E.; S.S.E.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—E. by S. ½ S.; S. by E. ½ E.; N.W. by W.; W. ½ S.

Correct magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at E. by S. ½ S., find the bearings, correct magnetic.

Compass bearings:—N.W. by W. ½ W. and S. by E. ½ E.

Bearings, magnetic:—

EXAMINATION PAPER—No. XVIII.

FOR SECOND MATE.

1. Multiply 84000 by 32000, and ·00087214 by ·001963, by common logarithms.
2. Divide 9504000 by 98, and ·9649 by 35·0583, by common logarithms.
3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	W.N.W.	12	6	North.	¼	10° W.	A point, lat. 36° 27′ S., long. 68° 37′ W., bearing by compass E. ¾ S., dist. 25 miles. Ship's head W.N.W. Deviation as per log.
2		12	6				
3		12	8				
4		13					
5	S.W. by W.	10	6	N.W. by W.	¾	7° W.	
6		10	4				
7		10	4				
8		10	6				
9	N. by E. ½ E.	7	3	N.W. ½ W.	1½	2½° W.	
10		7	6				
11		7	8				
12		7	3				Variation 22½° E.
1	N.W.	11	4	N.N.E.	½	8° W.	
2		11	4				
3		11	8				
4		11	4				
5	S.W. ½ W.	3	3	W.N.W.	3½	7° W.	
6		2	8				
7		2	6				A current set S.S.W. ½ W. (correct magnetic), 32 miles from the time the departure was taken to the end of the day.
8		2	3				
9	N.E. ½ E.	4	7	N. by W. ½ W.	2¾	8° E.	
10		4	4				
11		3	6				
12		3	3				

4. 1888, January 1st, in longitude 167° 54′ E., the obs. mer. alt. of the sun's L.L. was 83° 40′ 0″, bearing North, index error + 47″, height of eye 23 feet: required the latitude.

5. In latitude 60° 5′ the departure made good was 96 miles West: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 8° 57′ N.	Longitude of A 79° 31′ W.
Latitude of B 36 50 S.	Longitude of B 174 49 E.

7. 1885, March 1st: find the time of high water, A.M. and P.M., at Bembridge Point, Newhaven, Lowestoft, Lamlash, and Strangford Quay (Ireland).

8. 1887, November 4th, at $4^h 52^m 42^s$ A.M., apparent time at ship, in latitude 46° 40′ S., longitude 8° 57′ W., sun's bearing by compass S.E. ½ S.: required the true amplitude and error of compass; and supposing the variation to be 16° 30′ W.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, September 1st, A.M. at ship, latitude 15° 31′ S., observed altitude sun's L.L. 15° 18′ 20″, index correction — 20″, height of eye 26 feet, time by chronometer August $31^d 20^h 12^m 40^s$, which, on April 15th, was $1^m 30^s$ *slow* for mean noon at Greenwich, and on April 29th was $0^m 29^s$ *fast* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, June 1st, mean time at ship $8^h 19^m$ A.M., latitude 21° 10′ N., longitude 61° 30′ E., sun's magnetic azimuth E. ¾ N., observed altitude sun's L.L. 39° 10′ 0″, index error — 15″, height of eye 18 feet: required the true azimuth and error of the compass; and supposing the variation to be 0° 50′ E.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, April 13th, A.M. at ship, latitude by account 0, longitude 147° 10′ E., the observed altitude of the sun's L.L., North of the observer, was 80° 30′ 0″, index error + 1′ 10″, height of eye 16 feet, time by watch $0^h 0^m 12^s$, which had been found to be $11^m 1^s$ *fast* on apparent time at ship, the difference of longitude made to the East since the error of watch on apparent time at ship was determined was 8½ miles: required the latitude by reduction to meridian.

12. 1887, April 1st, A.M. at ship, and uncertain of my position, when a chronometer showed March $31^d 22^h 22^m 13^s$ M.T.G., observed altitude sun's L.L. 34° 52′ 40; again, P.M. at ship same day, when chronometer showed April $1^d 3^h 39^m 22^s$ M.T.G., observed altitude sun's L.L. 31° 20′ 30″, height of eye 17 feet, the ship having made 20 miles on a true S.W. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 51° N. and 50° 30′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel (True) Chart. Var. 21° W.

I. Using Deviation Card No. I, find the course to steer by compass from A to Ushant (east end); also the distance.

A, Latitude 49° 18′ N.	Longitude 3° 45′ W.

II. With the ship's head on the above-named compass course, Triagoz bore by compass S.E. by S., and Ile de Bas bore S. by W. ½ W. by the same compass: find the ship's position.

III. With the ship's head as above Ile de Bas bore by compass S. by W., and after continuing on the same course 20 miles it bore S.E. ¾ E.: find the position of the ship, and her distance from Ile de Bas at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from A to Ushant (see Question I) to counteract the effect of a current which set W. by S. ½ S. (true) at the rate of 4 miles an hour, the ship making by log 35 miles in 5 hours; also the distance the ship would then make good in 5 hours towards Ushant.

V. 1885, August 1st, at $2^h 30^m$ A.M., being off Ushant by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, May 10th, the obs. mer. alt. of star α^2 Centauri, South of observer, was 10° 4′ 15″, index corr. — 2′ 10″, height of eye 29 feet; required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 27° E.		South	S. 12° W.	
N.E.	South.		S.W.	S. 21 E.	
East	S. 21 W.		West	S. 37 E.	
S.E.	S. 27 W.		N.W.	S. 39 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—N. by E. ¾ E.; E. ½ N.; S.S.W. ¼ W.; N.W. ¼ N.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—N.W. ¼ N.; S.S.E. ½ E.; E. by N. ½ N.; N.N.E. ¾ E.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at S.E. ½ S., find the bearings, correct magnetic.

Compass bearings:—N.E. ½ E. and N. by W. ½ W.

Bearings, Magnetic:—

EXAMINATION PAPER—No. XIX.

FOR SECOND MATE.

1. Multiply 2410050 by 5, and 279·806 by 3100·5, by common logarithms.

2. Divide ·00001400018 by ·00000700009, and 2004·64 by 34, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					p. s.		
1	S. by E. ½ E.	12		E. ¾ S.	¼	19½° E.	A point, lat. 46° 20′ S., long. 176° 44′ W., bearing by compass E. by N. ¼ N., dist. 13 miles. Ship's head S. by E. ½ E. Deviation as per log.
2		11	6				
3		12	2				
4		12	2				
5	S. by W.	9	2	S.E. by E.	¾	25° E.	
6		9					
7		9	6				
8		9	4				
9	S.S.W. ¼ W.	7	5	West.	1¼	28° E.	
10		7	5				
11		7	6				
12		7	4				
1	W. by S.	11	3	N.W. by N.	½	21° E.	Variation 15° E.
2		10	8				
3		10	8				
4		10	6				
5	West.	9	8	N.N.W.	1	20° E.	
6		9	6				
7		9	4				A current set (correct magnetic) N.W. ½ W., 36 miles, from the time the departure was taken to the end of the day.
8		9	6				
9	N.N.W.	9	3	West.	¾	15½° W.	
10		9	4				
11		9	6				
12		9	5				

4. 1887, September 23rd, in long. 119° 54′ E., the obs. mer. alt. of the sun's L.L. was 83° 46′, zenith South of sun, index error — 5′ 30″, height of eye 18 feet: required the latitude.

5. In latitude 63° 54′ N., the departure made good was 63·5 miles: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 9° 59′ S. Longitude of A 140° 5′ W.
Latitude of B 10 0 N. Longitude of B 163 5 E.

7. 1885, November 20th: find the time of high water, A.M. and P.M., at Woolwich, Gibraltar, Cromarty, Crinan, and Batavia, long. 106° 48′ E.

8. 1887, August 1st, at $4^{h}\ 1^{m}$ A.M., apparent time at ship, in latitude 59° 7′ N., longitude 178° 14′ W., sun's bearing by compass N. 1° 30′ W.: required the true amplitude and error of the compass; and supposing the variation to be 19° 45′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, June 14th, P.M. at ship, latitude 31° 10′ N., observed altitude sun's L.L. 48° 59′ 10″, index correction + 1′, height of eye 18 feet, time by chronometer June $14^{d}\ 12^{h}\ 15^{m}\ 40^{s}$, which, on January 2nd, was $4^{m}\ 30^{s}$ *fast* for mean noon at Greenwich, and on March 13th was $9^{m}\ 16^{s}$ *fast* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1888, January 1st, P.M. at ship, latitude 31° 50′ S., longitude 176° 25′ E., sun's bearing by compass W. ½ N., observed altitude sun's L.L. 34° 50′, index correction 0, height of eye 16 feet, when a chronometer showed, 1887, December $31^{d}\ 16^{h}\ 24^{m}\ 20^{s}$ M.T.G.: required the true azimuth and error of the compass from altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 20° E.: required the deviation for the position of the ship's head.

11. 1887, December 31st, A.M. at ship, latitude by account 52° N., longitude 78° E., observed altitude sun's L.L., South of observer, was 14° 49′ 10″, index error — 3′ 10″, height of eye 19 feet, time by chronometer December $30^{d}\ 18^{h}\ 37^{m}\ 14^{s}$, which was $3^{m}\ 5^{s}$ *slow* on mean time at Greenwich: required the latitude by reduction to meridian.

12. 1887, January 24th, A.M. at ship, and uncertain of my position, when a chronometer showed January $23^{d}\ 21^{h}\ 19^{m}\ 50^{s}$ M.T.G., obs. alt. sun's L.L. 9° 34′ 50″; again, P.M. at ship same day, when chronometer showed January $24^{d}\ 1^{h}\ 19^{m}\ 12^{s}$, obs. alt. sun's L.L. 18° 28′ 10″, height of eye 17 feet, the ship having made 23 miles on a true S.E. by E. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 51° 15′ N. and 50° 45′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel Chart (*True*). Var. 21½° W.

I. Using Deviation Card No. II, find the course to steer by compass from A to Saltees, also the distance.

A, Latitude 51° 20′ N. Longitude 8° 30′ W.

II. With the ship's head on the above-named compass course Kinsale bore by compass N. 82½° W., and Ballycotton bore N. 4° W. by the same compass: find the ship's position.

III. With the ship's head as above Minehead bore by compass N. 4° W., and after continuing on the same course 20 miles it bore W. by N. ½ N.: find the position of the ship, and her distance from Minehead at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from A to Saltees (see Question I) to counteract the effect of a current which set N.E. (magnetic), at the rate of 3 miles per hour, the ship making by log 48 miles in 6 hours; also the distance the ship would then make good in 6 hours towards Saltees.

V. 1885, January 10th, at $8^{h}\ 52^{m}$ A.M., being off Kinsale, Coast of Ireland, by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, April 11th, the observed meridian altitude of star Sirius, North of observer, was 61° 3′ 50″, index corr. 0, height of eye 16 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation:—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 27° E.		South	S. 12° W.	
N.E.	South.		S.W.	S. 21 E.	
East......	S. 21 W.		West	S. 37 E.	
S.E.	W. 63 S.		N.W.	E. 51 S.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—N. by E. ¾ E.; E. ½ N.; S.S.W. ¼ W.; N.W. ¼ N.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—N.W. ¼ N.; S.S.E. ½ E.; E. by N. ½ N.; N.N.E. ¾ E.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at N.E. ½ E., find the bearings, correct magnetic.

Compass bearings:—N.E. ½ E., and N. by W. ½ W.

Bearings, magnetic:—

EXAMINATION PAPER—No. XX.

FOR SECOND MATE.

1. Multiply 1000·025 by 1·0625, and ·034632 by ·397302, by common logarithms.
2. Divide 8100900 by 900, and ·00005 by 2·5, by 25, and by ·0000025, by common logs.
3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way. pts.	Deviation.	Remarks, &c.
1	N.E. ½ E.	13	2	N. by W. ½ W.	¼	26° E.	A point, lat. 50° 25′S., long. 179°40′E., bearing by compass N. by W. ¼ W., dist. 16 miles. Ship's head N.E. ½ E. Deviation as per log.
2		12	9				
3		13	5				
4		13	4				
5	W.S.W.	3	6	N.W.	2¼	4½° W.	
6		4					
7		4					
8		3	4				
9	E. by N.	12	2	N. by E.	½	28° W.	
10		12	4				
11		12	6				
12		12	8				
1	N. by W. ½ W.	2	4	N.E. ½ E.	3	51° E.	
2		2	3				Variation 14° E.
3		2	3				
4		2					
5	S. ¾ W.	6	9	W. by S.	¼	50° W.	
6		6	8				
7		6	8				
8		7	5				A current set E.N.E. (correct magnetic) 52 miles from the time the departure was taken to the end of the day.
9	E. by N. ½ N.	11	5	N. by E. ½ E.	¾	28° W.	
10		12	2				
11		11	6				
12		11	7				

4. 1887, September 23rd, in longitude 57° 45′ E., the obs. mer. alt. of sun's L.L. was 84° 10′ 50″, bearing North, index error — 1′ 36″, height of eye 16 feet: required the latitude.

5. In latitude 52° S., the departure made good was 136 miles due East: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A	5° 21′ N.	Longitude of A	163° 1′ E.
Latitude of B	36 50 S.	Longitude of B	73 6 W.

7. 1885, August 22nd: find the time of high water, A.M. and P.M., at Cadiz, Arbroath, Dunbar, and Westport (Ireland).

8. 1887, November 5th, at $5^h\ 10^m$ P.M., apparent time at ship, latitude 20° 45′ N., longitude 116° 45′ E., sun's bearing by compass S.W. ¾ W.: required the true amplitude and error of compass; and supposing the variation to be 1° 0′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, August 5th, A.M. at ship, latitude 30° 30′ N., observed altitude sun's L.L. 35° 6′ 0″, index correction 0, height of eye 16 feet, time by chronometer $8^h\ 39^m\ 22^s$ P.M., which, on July 8th, was $29^m\ 32^s{\cdot}4$ *fast* for mean noon at Greenwich, and on July 20th was 30^m *fast* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, August 13th, mean time at ship $9^h\ 5^m\ 20^s$ A.M., latitude 30° 46′ S., longitude 78° 50′ W., sun's magnetic azimuth N. 25° E., observed altitude sun's L.L. 27° 12′ 0″, index error + 1′ 45″, height of eye 21 feet,: required the true azimuth and error of the compass; and supposing the variation to be 16° 20′ E.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, June 12th, P.M. at ship, latitude by account 15° 50′ S., long. 72° 12′ E., the observed altitude of sun's L.L., North of observer, was 50° 10′ 10″, index correction — 5′ 40″, height of eye 26 feet, time by watch $12^d\ 0^h\ 28^m\ 40^s$, which had been found to be $4^m\ 44^s$ *slow* on apparent time at ship, the difference of longitude made to the West since the error of watch on apparent time at ship was determined was 16½ miles: required the latitude by reduction to meridian.

12. 1887, November 3rd, A.M. at ship, and uncertain of my position, when a chronometer showed November $2^d\ 22^h\ 38^m\ 45^s$ M.T.G., observed altitude sun's L.L. 18° 53′ 50″; again, P.M. at ship same day, when chronometer showed November $3^d\ 2^h\ 44^m\ 15^s$, observed altitude sun's L.L. 16° 32′ 30″, height of eye 19 feet, the ship having made 15 miles on a true E. by S. ½ S. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 51° 45′ N. and 51° 15′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Outline English Channel Chart (True). Var. 21½° W.

I. Using Deviation Card No. II, find the course to steer by compass from A to Smalls, also the distance.

A, Latitude 51° 58′ N. Longitude 7° 15′ W.

II. With the ship's head on the above-named compass course, Hook Point bore by compass N.N.E. ¾ E., and Satlees bore E. by N. by the same compass: find the ship's position.

III. With the ship's head as above Saltees bore by compass N.E. ¾ E., and after continuing on the same course 15 miles it bore N. by W. ½ W.: find the position of ship, and her distance from Saltees at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from A to Smalls (see Question I) to counteract the effect of a current which set N.E. by E. ½ E. (true) at the rate of 3 miles per hour, the ship making by log 24 miles in 4 hours; also the distance the ship would then make good in 4 hours towards Smalls.

V. 1885, February 9th, at $11^h\ 0^m$ A.M., being off the Saltees' light, by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, December 7th, the obs. mer. alt. of star α Arietis, South of observer, was 60° 29′ 50″, index correction — 2′ 10″, height of eye 18 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation:—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 51°W.		South	N. 30°W.	
N.E.	W. 6 S.		S.W.	W. 21 N.	
East......	N. 57 W.		West	W. 8 S.	
S.E.......	W. 64 N.		N.W.	S. 46 W.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—W. ¾ N.; S.E. ½ E.; N. by E. ½ E.; S. by E. ¾ E.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—E. ¼ N.; S. by W. ¼ W.; N.W. ¾ W.; S.W. by W. ½ W.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at S.E. ½ E., find the bearings, correct magnetic.

Compass bearings:—S. ½ W.; W. by N. ¼ N.; and E. ¼ N.

Bearings, magnetic:—

EXAMINATION PAPER—No. XXI.

FOR SECOND MATE.

1. Multiply 7642 by 7429·5, and ·00064 by 10·0004, by common logarithms.
2. Divide ·39765 by 25, and 1000000 by ·0000001, by common logarithms.
3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	N. by W.	6	4	W. by N.	1½	8° W.	A point, lat. 57° N., long. 40° W., bearing by compass N.E. by E. ½ E., dist. 19 miles. Ship's head N. by W. Deviation as per log.
2		6	3				
3		5	6				
4		5	4				
5	S.S.W. ¾ W.	4	8	W. ½ N.	2¼	5° W.	
6		4	2				
7		3	7				
8		3	6				
9	N.N.E. ¾ E.	4	2	N.W. ¾ N.	2	13° E.	
10		4	4				
11		4	5				
12		4	5				
1	W. by N.	3	4	N. by W.	2½	17½° W.	Variation 48° W.
2		3	4				
3		3	6				
4		3	7				
5	S.E. ¾ E.	9	5	S.S.W.	¼	11° E.	
6		10	5				
7		11	2				
8		10	8				A current set (correct magnetic) W.N.W., 15 miles, from the time the departure was taken to the end of the day.
9	S. ½ W.	3	2	W.S.W.	2¾	2° W.	
10		3	3				
11		2	8				
12		2	7				

4. 1887, June 25th, in longitude 59° 15′ E., the obs. mer. alt. of the sun's U.L. was 60° 23′ 15″, bearing North, index error + 2′ 21″, height of eye 30 feet: required the latitude.

5. In latitude 38° 46′, the departure made good was 120 miles West: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from (A) Cape East, New Zealand, to (B) San Francisco, by calculation on Mercator's principle.

Latitude of A 37° 40′ S. Longitude of A 178° 36′ E.
Latitude of B 37 48·5 N. Longitude of B 122 24 W.

7. 1885, August 19th: find the time of high water, A.M. and P.M., at Skull, Tarbert, New Ross, and Sandy Hook (New York), long. 74° W.

8. 1887, June 24th, at 6^h A.M., apparent time at ship, in latitude 0°, longitude 12° 3′ W., sun's bearing by compass S.E. by E. ½ E.: required the true amplitude and error of compass; and supposing the variation to be 21° 40′ W.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, September 22nd, A.M. at ship, lat. 0°, observed altitude sun's U.L. 17° 20′ 40″, index corr. — 1′ 18″, height of eye 20 feet, time by chronometer September $22^d\ 4^h\ 59^m\ 16^s$, which, on April 30th, was 15^s *slow* for mean noon at Greenwich, and on June 1st was $10^s{\cdot}6$ *fast* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, March 21st, mean time at ship $3^h\ 15^m$ P.M., latitude 9° 7′ S., longitude 159° 4′ W., sun's magnetic azimuth W. ½ S., observed altitude sun's L.L. 42° 49′ 45″, index correction — 3′ 14″, height of eye 21 feet: required the true azimuth and error of the compass; and supposing the variation to be 7° 50′ E.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, October 4th, A.M. at ship, latitude by account 30° 24′ S., longitude 140° 30′ E., the observed altitude of the sun's L.L., North of the observer, was 63° 37′ 10″, index correction — 1′ 15″, height of eye 21 feet, time by watch October $3^d\ 22^h\ 37^m\ 15^s$, which had been found to be $1^h\ 10^m\ 20^s$ *slow* on apparent time at ship, the difference of longitude made to the East since the error of watch on apparent time at ship was determined was 23½ miles: required the latitude by reduction to meridian.

12. 1887, January 16th, A.M. at ship, and uncertain of my position, when a chronometer showed January $16^d\ 7^h\ 7^m\ 58^s$ M.T.G., observed altitude sun's L.L. 13° 10′ 30″; again, P.M. at ship same day, when chronometer showed January $16^d\ 11^h\ 22^m\ 8^s$, observed altitude sun's L.L. 15° 17′ 30″, height of eye 17 feet, the ship having made 36 miles on a true N.E. by E. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 49° 0′ N., and 49° 40′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Outline English Channel Chart (True). Var. 19½° W.

I\. Using Deviation Card No. I, find the course to steer by compass from Manacle Point to Ram Head, also the distance.

II\. With the ship's head on the above-named compass course St. Anthony's Point bore by compass N.W. ½ N., and Dodman Point bore North by the same compass: find the ship's position.

III\. With the ship's head as above St. Anthony's Point bore by compass N.N.W., and after continuing on the same course 10 miles it bore N.W. by W.: find the position of the ship, and her distance from St. Anthony's Point at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV\. Find the course to steer by compass from Manacle Point to Ram Head (see Question I) to counteract the effect of a current which set E. by S. (true) at the rate of 2½ miles per hour, the ship making by log 9 miles an hour; also the distance the ship would make good in 2 hours towards Ram Head.

V\. 1885, January 10th, $2^h\ 18^m$ A.M., being off Falmouth by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, June 10th, the obs. mer. alt. of star α Cassiopeæ, South of observer, was 85° 0′ 20″, index correction + 34″, height of eye 18 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 78°E.		South	S. 89°E.	
N.E.	E. 22 S.		S.W.	N. 66 E.	
East	E. 34 S.		West	E. 23 N.	
S.E.	E. 29 S.		N.W.	N. 79 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—N. ¾ E.; E. ¼ S.; S. ½ E.; W. ¼ S.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—N.E. ½ E.; S.S.E. ½ E.; W. ½ N.; N. by W. ¼ W.

Correct magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with ship's head at S.W. by W. ½ W., find the bearings, correct magnetic.

Compass bearings:—N.E. ½ N. and E. ½ N.

Bearings, magnetic:—

EXAMINATION PAPER—No. XXII.

FOR SECOND MATE.

1. Multiply 3846·2 by 295·64, and 68250625 by ·07638, by common logarithms.
2. Divide 6858009 by 2·766407, and 120500 by 120·5, by common logarithms.
3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	W.N.W.	13	4	S.E.	0	43½° E.	A point, lat. 51°8½' N., long. 1° 25' E., bearing by compass S.W. ¾ S., dist. 25 miles. Ship's head W.N.W. Deviation as per log.
2		13					
3		13	6				
4		10					
5	W. ½ S.	9	6	S.S.W.	½	43° E.	
6		9	4				
7		9	5				
8		9	5				
9	West.	8	4	N.N.W.	¾	43½° E.	
10		8	4				
11		8	4				
12		8	6				
1	N. ¾ E.	9	5	N.W. by W.	½	17½° E.	Variation 25° W.
2		9	4				
3		9	6				
4		9	4				
5	North.	10	5	W.N.W.	¼	19° E.	
6		10	6				
7		11					A current set the ship N.W. by W ¾ W. correct magnetic), 32 miles from the time the departure was taken to the end of the day.
8		10	4				
9	N.W. ½ W.	7	4	N. by E. ½ E.	1¼	44° E.	
10		7					
11		7	4				
12		7	2				

4. 1887, August 26th, in longitude 92° 3′ E., observed meridian altitude sun's L.L. was 35° 35′ 20″ bearing North, index error + 2′ 17″, height of eye 12 feet: required the latitude.

5. In latitude 17° 15′ N., the departure made good was 171·5 miles: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A	55° 40′ N.	Longitude of A	2° 25′ W.
Latitude of B	50 25 N.	Longitude of B	3 40 E.

7. 1885, June 22nd: find the time of high water, A.M. and P.M., at Flambro' Head, Peterhead, Crinan, St. Ives, Cape Wrath, and Whitby.

8. 1887, September 23rd, at $6^h\ 0^m$ P.M., apparent time at ship, in latitude 51° 3′ S., longitude 152° 17′ E., sun's bearing by compass W. 15° S.: required the true amplitude and error of compass; and supposing the variation to be 20° 16′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, August 28th, P.M. at ship, latitude 5° S., observed altitude sun's L.L. 38° 0′ 0″, index correction + 5′ 20″, height of eye 21 feet, time by chronometer August $27^d\ 22^h\ 20^m\ 30^s$, which, on February 19th, was 10^m *slow* for mean noon at Greenwich, and on May 30th was $2^m\ 20^s$ *slow* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, June 15th, mean time at ship $7^h\ 32^m$ P.M., latitude 59° 55′ N., longitude 75° 17′ E., sun's magnetic azimuth N. ½ E., observed altitude sun's L.L. 9° 15′ 40″, index error 0, height of eye 17 feet: required the true azimuth and error of the compass; and supposing the variation to be 50° 40′ W.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, August 28th, P.M. at ship, latitude by account 73° 20′ N., longitude 88° 39′ W., observed altitude sun's L.L., South of observer, was 26° 13′ 40″, index error — 1′ 30″, height of eye 26 feet, time by watch $28^d\ 0^h\ 50^m\ 58^s$, which had been found to be $26^m\ 58^s$ *fast* on apparent time at ship, the difference of longitude made to the West since the error of watch on apparent time at ship was determined was 21′·3: required the latitude by reduction to meridian.

12. 1887, August 9th, A.M. at ship, and uncertain of my position, when a chronometer showed August $8^d\ 16^h\ 12^m\ 1^s$ M.T.G., observed altitude sun's L.L. 50° 30′ 10″; again, P.M. at ship same day, when chronometer showed August $8^d\ 19^h\ 51^m\ 47^s$, observed altitude sun's L.L. 52° 50′ 0″, height of eye 21 feet, the ship having made 32 miles on a true S. by W. ¾ W. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 46° 30′ N. and 46° 0′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel (Magnetic) Chart. Var. 19½° W.

I. Using Deviation Card No. I, find the course to steer by compass from the Lizard to the Start, also the distance.

II. With the ship's head on the above-named compass course the Lizard Lights bore by compass W. ¾ N., and St. Anthony's bore by the same compass N.N.E. ½ E.: find the ship's position.

III. With the ship's head as above, St. Anthony's bore by compass N.E., and after continuing on the same course 14 miles it bore N.W.: find the position of the ship and her distance from St. Anthony's at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from the Lizard to the Start (see Question I) to counteract the effect of a current which set W. by S., magnetic, at the rate of 1½ mile per hour, the ship making by log 40 miles in 4 hours, also the distance the ship would then make good in 4 hours towards the Start.

V. 1885, December 22nd, at $6^h\ 54^m$ A.M., being off the Lizard by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, September 11th, the observed meridian altitude of star α Cassiopeæ, North of observer, was 62° 24′ 50″, index correction — 7′ 30″, height of eye 19 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation:—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 44°W.		South	S. 17°W.	
N.E.	S. 45 W.		S.W.	South.	
East......	S. 45 W.		West	S. 14 W.	
S.E.	S. 40 W.		N.W.	S. 35 W.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—S.W.; N. 15° E.; E.S.E.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—S.W.; West; E. by N.

Correct magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at North, find the bearings, correct magnetic.

Compass bearings:—North and E. ½ N.

Bearings, magnetic:—

EXAMINATION PAPER—No. XXIII.

FOR SECOND MATE.

1. Multiply 81000 by 25000, and 80400 by 325, by common logarithms.

2. Divide 9869·25 by ·075, and 100000 by ·125, and by ·00125 by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
1	W. ½ N.	8	2	N. by W.	pts. ¾	24° W.	A point, lat. 62° 10′ N., long. 178° 52′ W., bearing by compass E.N.E., dist. 12 miles. Ship's head W. ½ N. Deviation as per log.
2		7	8				
3		8	8				
4		9	2				
5	W. by S.	7	8	S. by W.	1¾	21° W.	
6		7	6				
7		7	6				
8		7					
9	S.W. by W.	7	6	S. by E.	1	16° W.	
10		7	8				
11		8	8				
12		7	8				
1	S.S.W.	8	8	S.E.	½	7° W.	Variation 20° W.
2		8	8				
3		9					
4		7	4				
5	S. by E.	7		E. by S.	2¼	3° E.	
6		8	4				
7		8	6				
8		8					A current set (correct magnetic) W. by S., 30 miles, from the time the departure was taken to the end of the day.
9	S.S.E.	8	4	East.	1½	7° E.	
10		8	6				
11		9					
12		8					

4. 1887, September 1st, in longitude 97° 42′ E., the obs. mer. alt. of the sun's L.L. was 51° 4′ 50″, observer South of sun, index error — 6′, height of eye 23 feet: required the latitude.

5. In latitude 2° 10′ N., the departure made good was 210 miles: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 58° 30′ S.	Longitude of A 147° 40′ W.
Latitude of B 40 58 N.	Longitude of B 176 59 E.

7. 1885, December 1st: find the time of high water, A.M. and P.M. at Arcachon, Falmouth, Bridlington, Padstow, Courtmacsherry, and Port Royal, long. 77° W.

8. 1887, December 24th, at 10^h 51^m A.M., apparent time at ship, in latitude 64° 56′ N., longitude 35° 48′ W., sun's bearing by compass S. ½ W.: required the true amplitude and error of compass; and supposing the variation to be 1° 20′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, April 15th, A.M. at ship, latitude 48° 52′ N., observed altitude sun's L.L. 22° 18′, index corr. — 4′ height of eye 17 feet, time by chronometer April 14^d 22^h 30^m 42^s, which, on January 12th, was 0^m 2^s *fast* for mean noon at Greenwich, and *gaining* $0^s{\cdot}55$ daily: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, September 23rd, P.M. at ship, latitude 40° 0′ N., longitude 162° 10′ E., sun's bearing by compass W. ½ S., observed altitude sun's L.L. 31° 59′ 50″, index corr. + 8′ 30″, height of eye 20 feet, when a chronometer showed September 22^d 16^h 6^m 20^s M.T.G.: required the true azimuth and error of the compass from altitude, and also from "Time Azimuth Tables;" and supposing the variation to be 20° W.: required the deviation for the position of the ship's head.

11. 1887, September 22nd, P.M. at ship, latitude by acct. 40° 35′ N., longitude 121° 34′ W., the observed altitude of the sun's L.L., South of the observer, was 49° 26′ 30″, index error — 6′ 15″, height of eye 15 feet, time by chronometer September 22^d 8^h 7^m 57^s, which was 3^m 15^s *slow* on mean time at Greenwich: required the latitude by reduction to meridian.

12. 1887, November 26th, A.M. at ship, and uncertain of my position, when a chronometer showed November 26^d 2^h 39^m 15^s M.T.G., observed altitude sun's L.L. 11° 20′; again, P.M. at ship same day, when chronometer showed November 26^d 6^h 49^m 49^s M.T.G., observed altitude sun's L.L. 16° 35′ 10″, height of eye 23 feet, the ship having made 12 miles on a true S.W. ¾ W. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 49° 0′ N. and 49° 30′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel Chart (True). Var. 18° W.

I. Using Deviation Card No. I, find the course to steer by compass from Bembridge Point to Fecamp, also the distance.

II. With the ship's head on the above-named compass course the Nab light bore by compass N. ¼ E., and the Owers bore E. by S. by the same compass: find the ship's position.

III. With the ship's head as above the Owers bore by compass E. ¾ N., and after continuing on the same course 10 miles it bore N.N.E. ½ E.: find the position of the ship, and her distance from the Owers at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from Bembridge Point to Fecamp (or from A to B) (see Question I) to counteract the effect of a current which set N.W. (true) at the rate of 2½ miles an hour, the ship making by log 10 miles an hour; also the distance the ship would make good in 3 hours and in 1 hour towards Fecamp.

V. 1885, February 1st, at 3^h 16^m P.M., mean time at ship, being off Fecamp by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, August 20th, the obs. mer. alt. of star β Centauri, South of observer, was 59° 49′ 13″, index corr. — 2′, height of eye 25 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 78° E.		South	N. 44° E.	
N.E.	N. 68 E.		S.W.	N. 67 E.	
East......	N. 37 E.		West	East.	
S.E.......	N. 36 E.		N.W.	S. 80 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct Magnetic courses:—E. ¾ S.; N.E.; N. by W. ½ W.; S. by W. ¾ W.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—S.W.; W. ½ N.; S. ¾ E.; N.E. ½ E.

Correct magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at N. by E. ¾ E., find the bearings, correct magnetic.

Compass bearings:—South and N. ¾ E.

Bearings, magnetic:—

EXAMINATION PAPER—No. XXIV.

FOR SECOND MATE.

1. Multiply 41375 by 240, and 3·86007 by ·002973, by common logarithms.
2. Divide 900009 by 100001, and 306250 by 1·75, by common logarithms.
3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					pts.		
1	E. ¼ S.	12	4	North.	0	16½° E.	A point, lat. 37°45′ N., long. 0° 58′ W., bearing by compass W. ½ N., dist. 42 miles. Ship's head E. ¼ S. Deviation as per log.
2		13					
3		13	6				
4		14					
5	E. by N.	12		N. by E.	½	18½° E.	
6		11	4				
7		11	6				
8		12					
9	S.S.E.	5	4	East.	2¼	11° E.	
10		5	5				
11		5	6				
12		5	5				
1	N.N.E.	3	4	East.	3¼	6° W.	Variation 14° W.
2		3					
3		3	6				
4		4					
5	E. ½ N.	9	5	N. by E. ½ E.	½	20½° E.	
6		9	5				
7		9					
8		9					A current set E.S.E. (correct magnetic), 52½ miles from the time the departure was taken to the end of the day.
9	E.S.E.	8	4	N.E.	¾	12½° E.	
10		8	6				
11		9					
12		9					

4. 1887, December 1st, in longitude 67° 56′ E., the obs. mer. alt. of the sun's L.L. was 18° 48′ 10″, bearing South, index error — 3′ 6″, height of eye 18 feet: required the latitude.

5. In latitude 37° 45′ S. the departure made good was 208·9 miles: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 5° 28′ S.	Longitude of A 35° 17′ W.
Latitude of B 15 13 N.	Longitude of B Meridian of Greenwich.

7. 1885, April 10th: find the time of high water, A.M. and P.M., at Morlaix, Ile de Sein, Ecrehous, Penzance, Limerick, Dunmanus Harbour, and Hobart (Tasmania), long. 147° 22′ E.

8. 1887, February 1st, at $11^h\ 18^m$ P.M., apparent time at ship, in latitude 72° 58′ S., longitude 88° 59′ 45″ W., sun's bearing by compass S. ½ E.: required the true amplitude and error of compass; and supposing the variation to be 36° 20′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, August 31st, P.M. at ship, latitude on the Equator, observed altitude sun's L.L. 45° 5′ 30″, index correction — 2′ 10″, height of eye 15 feet, time by chronometer August $31^d\ 9^h\ 11^m\ 28^s$, which, on April 15th, was $5^m\ 20^s$ *fast* for mean noon at Greenwich, and on June 16th was $2^m\ 43^s$ *fast* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, June 15th, mean time at ship $7^h\ 11^m\ 41^s$ P.M., latitude 55° 1′ N., longitude 70° 12′ E., sun's bearing by compass N. ½ E., observed altitude sun's L.L. 9° 15′ 40″, index error 0, height of eye 17 feet: required the true azimuth and error of the compass; and supposing the variation to be 50° 40′ W.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, March 21st, P.M. at ship, latitude by account 18° 50′ N., longitude 108° 47′ E., the observed altitude of the sun's L.L., South of the observer, was 71° 9′ 50″, index error — 3′, height of eye 18 feet, time by watch March $20^d\ 23^h\ 58^m\ 12^s$, which had been found to be $11^m\ 8^s$ *slow* on apparent time at ship, the difference of longitude made to the East since the error of watch on apparent time at ship was determined was 18½ miles: required the latitude by reduction to meridian.

12. 1887, August 17th, A.M. at ship, and uncertain of my position, when a chronometer showed August $16^d\ 8^h\ 0^m\ 20^s$ M.T.G., observed altitude sun's L.L. 28° 14′ 10″; again, P.M. at ship same day, when chronometer showed August $16^d\ 14^h\ 0^m\ 20^s$ M.T.G., observed altitude sun's L.L. 46° 21′, height of eye 12 feet, the ship having made 20 miles on a true East course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 49° 30′ N. and 50° 0′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Using Outline English Channel (*True*) *Chart.* Var. 21½° W.

I. Using Deviation Card No. I, find the course to steer by compass from Kinsale Head to Smalls Light; also the distance.

II. With the ship's head on the above-named compass course, Daunt's Rock Light bore by compass N. by W. ½ W., and Ballycottin Light bore by the same compass N.E. ½ E.: find the ship's position.

III. With the ship's head as above Ballycottin bore E. ½ N., and after continuing on the same course 17½ miles it bore N. by E.: find the position of the ship, and her distance from Ballycottin at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from Kinsale to Smalls (or from A to B) (see Question I) to counteract the effect of a current which set E.N.E. (true) at the rate of 1½ mile an hour, the ship making by log 3½ miles an hour; also the distance the ship would then make good in 2 hours, and in 1 hour towards Smalls.

V. 1885, March 6th, at $6^h\ 32^m$ A.M., off Ballycottin by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, March 31st, the obs. mer. alt. of star α Pegasi (*Markab*), North of observer, was 33° 20′ 50″, index corr. + 1′ 20″, height of eye 20 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation.

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 17° E.		South	N. 25° E.	
N.E.	N. 7 W.		S.W.	N. 45 E.	
East	N. 9 W.		West	N. 52 E.	
S.E.	North.		N.W.	N. 41 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—E. ¾ S.; W. by N. ¾ N.; S.E.; W. by S. ½ S.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—N.E. ½ N.; N. ½ W.; S. ¼ W.; W. ½ N.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at S.W. by W., find the bearings, correct magnetic.

Compass bearings:—E. ¾ S. and S. ½ W.

Bearings, Magnetic:—

EXAMINATION PAPER—No. XXV.

FOR SECOND MATE.

1. Multiply 6054 by 912, and 2070·5 by 62·0898, by common logarithms.
2. Divide 117·658 by 146·932, and 3729·08 by ·08378, by common logarithms.
3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way.	Deviation.	Remarks, &c.
					p. s.		
1	S. ½ W.	4	5	W. by S.	2¼	50° W.	A point, lat. 62° 20′ N., long. 64° 40′ W., bearing by compass W. by N. ½ N., dist. 21 miles. Ship's head S. ½ W. Deviation as per log.
2		4	2				
3		4					
4		3	9				
5	S.W. ¾ W.	3	5	S. by E.	3½	9° W.	
6		3	4				
7		3	2				
8		3	3				
9	E. ¾ S.	5	4	S. by E.	1¼	25° W.	
10		5	3				
11		4	4				
12		4	2				
1	W.N.W.	3	6	North.	3	37° E.	
2		4	5				Variation 59° W.
3		5	3				
4		5	7				
5	N.W. ½ N.	10	6	E.N.E.	0	28½° E.	
6		11	4				
7		12	6				
8		13	4				A current set (correct magnetic) E. by S. ½ S., 49 miles from the time the departure was taken to the end of the day.
9	E. ¾ N.	5	5	N. by E.	3½	26½° W.	
10		5	4				
11		5	4				
12		5					

4. 1887, June 1st, in longitude 44° 40′ E., the obs. mer. alt. of sun's L.L. was 72° 14′ 10″, bearing North, index error + 3′ 45″, height of eye 22 feet: required the latitude.

5. In latitude 32° 3′ S., the departure made good was 54 miles due West, then 80 miles North: required the difference of longitude by parallel sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 50° 33′ N. Longitude of A 156° 46′ E.
Latitude of B 12 4 S. Longitude of B 77 14 W.

7. 1885, January 29th: find the time of high water, A.M. and P.M., at Aberdeen, Montrose, Ramsgate, Fecamp, and Chatham.

8. 1887, December 21st, at 11^{h} 15^{m} P.M., apparent time at ship, latitude 66° 25′ S., longitude 93° 57′ W., sun's bearing by compass S. ¼ E.: required the true amplitude and error of compass; and supposing the variation to be 28° 10′ E.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, January 29th, P.M. at ship, latitude 28° 45′ N., observed altitude sun's L.L. 17° 46′ 30″, index correction — 3′ 25″, height of eye 16 feet, time by chronometer January 28^{d} 16^{h} 31^{m} 30^{s}, which, on December 17th, 1886, was 1^{m} $16^{s}.5$ *fast* for mean noon at Greenwich, and on January 1st, 1887, was 1^{m} 3^{s} *slow* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, July 10th, mean time at ship 3^{h} 14^{m} 2^{s} P.M., latitude 38° 2′ S., longitude 140° 58′ E., sun's magnetic azimuth N. 2° 15′ E., observed altitude sun's U.L. 14° 56′ 30″, index error + 3′ 30″, height of eye 19 feet,: required the true azimuth and error of the compass; and supposing the variation to be 6° 45′ E.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, November 29th, P.M. at ship, latitude by account 6° 20′ S., long. 123° 25′ E., the observed altitude of sun's L.L., South of observer, was 74° 0′ 0″, index correction + 4′ 0″, height of eye 19 feet, time by watch November 28^{d} 22^{h} 46^{m} 0^{s}, which had been found to be 1^{h} 27^{m} 0^{s} *slow* on apparent time at ship, the difference of longitude made to the West since the error of watch on apparent time at ship was determined was 12.3 miles: required the latitude by reduction to meridian.

12. 1887, October 20th, P.M. at ship, and uncertain of my position, when a chronometer showed October 19^{d} 16^{h} 30^{m} 54^{s} M.T.G., observed altitude sun's L.L. 29° 37′ 15″; again, P.M. at ship same day, when chronometer showed October 19^{d} 19^{h} 44^{m} 50^{s}, observed altitude sun's L.L. 12° 21′ 0″, height of eye 20 feet, the ship having made 24 miles on a true N.N.E. ½ E. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 49° 20′ N. and 49° 50′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Outline English Channel Chart (True). Var. 21½° W.

I. Using Deviation Card No. I, find the course to steer by compass from Lundy Island to Breaksea Point, also the distance.

II. With the ship's head on the above-named compass course, Ilfracombe bore by compass W. ¼ N., and Scarweather lightvessel bore N.E. by E. ¼ E. by the same compass: find the ship's position.

III. With the ship's head as above Scarweather lightvessel bore by compass E. *b* N. ¼ N., and after continuing on the same course 15 miles it bore N. ½ W.: find the position of the ship, and her distance from Scarweather lightvessel at the time of taking the second bearing.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from Lundy Island to Breaksea Point (or from A to B) (see Question I) to counteract the effect of a current which set W. by S. ¾ S. (true) at the rate of 2 miles per hour, the ship making by log 20 miles in 4 hours towards Breaksea Point.

V. 1885, April 23rd, at 10^{h} 28^{m} A.M., being off Nash Point by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, May 15th, the obs. mer. alt. of star β Orionis, South of observer, was 52° 30′ 30″, index correction — 4′ 10″, height of eye 15 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation:—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	S. 23°E.		South	S. 6°W.	
N.E.	S. 11 E.		S.W.	S. 18 E.	
East......	S. 5 W.		West	S. 21 E.	
S.E.......	S. 20 W.		N.W.	S. 22 E.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses:—S. ½ W.; E. by N.; S.E. by S.; W. by N.

Compass courses:—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses:—N.W. by N.; W.N.W.; S.E. by E.; N.N.E.

Magnetic courses:—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at S.E. by S., find the bearings, correct magnetic.

Compass bearings:—N. 84° W., and N.W. by W. ½ W.

Bearings, magnetic:—

EXAMINATION PAPER—No. XXVI.

FOR SECOND MATE.

1. Multiply 6893 by 11300, and ·0001468 by ·000395, by common logarithms.
2. Divide 7122 by 8·9596, and 268430 by ·00310, by common logarithms.

3.—

H.	Courses.	K.	$\frac{1}{10}$	Winds.	Lee-way. pts.	Deviation.	Remarks, &c.
1	S.E. ¼ E.	13	7	N.E. by E. ½ E.	¼	11° E.	A point, lat. 59° 49′ N., long. 44° 10′ W., bearing by compass N.W. ¼ W., dist. 30 miles. Ship's head S.E. ¼ E. Deviation as per log.
2		14					
3		13	2				
4		13	3				
5	E. ½ S.	10	4	S. by E. ½ E.	¾	14° E.	
6		10	4				
7		10	5				
8		10	3				
9	N. by W. ½ W.	4		N.E. ½ E.	2¼	8½° W.	
10		3	6				
11		3	4				
12		3	4				
1	S.S.W. ½ W.	11	6	S.E. ½ S.	½	2½° W.	Variation 53½° W.
2		11	7				
3		11	8				
4		11	4				
5	N.E. ¼ N.	7	2	E. by S. ½ S.	1	14° E.	
6		7	3				
7		7	4				
8		7	2				A current set (correct magnetic) S.E. ¼ E., 40·8 miles from the time the departure was taken to the end of the day.
9	S. ¼ E.	12	5	E.S.E.	¼	3° E.	
10		12					
11		12	3				
12		12	4				

4. 1887, October 1st, in longitude 84° 40′ E., the obs. mer. alt. of the sun's U.L. was 57° 20′ 30″, bearing South, index error — 3′ 36″, height of eye 17 feet: required the latitude.

5. In latitude 35° 30′ S., the departure made good was 301 miles: required the difference of longitude by Parallel Sailing.

6. Required the course and distance from A to B, by calculation on Mercator's principle.

Latitude of A 46° 12′ S.	Longitude of A 175° 50′ E.
Latitude of B 46 53 N.	Longitude of B 174 59 E.

7. 1885, December 17th: find the time of high water, A.M. and P.M., at Santander, Arcachon, Scarborough, Holy Island, Montrose, and Angra Pequena, long. 15° E.

8. 1887, April 25th, at $7^h\ 22^m\ 8^s$ P.M., apparent time at ship, in latitude 57° 18′ S., longitude 101° 50′ E., sun's bearing by compass N. ½ E.: required the true amplitude and error of compass; and supposing the variation to be 35° 50′ W.: required the deviation of the compass for the position of the ship's head at the time of observation.

9. 1887, August 24th, A.M. at ship, lat. 37° 38′ 18″ N., observed altitude sun's L.L. 37° 13′ 30″, index corr. + 2′ 40″, height of eye 18 feet, time by chronometer August $24^d\ 6^h\ 13^m\ 24^s$ A.M., which, on August 1st, was $1^m\ 5^s$ *fast* for mean noon at Greenwich, and on August 10th was $0^m\ 42^s$ *slow* for mean noon at Greenwich: required the longitude by chronometer.

ADDITIONAL FOR ONLY AND FIRST MATES.

10. 1887, November 1st, mean time at ship $8^h\ 27^m\ 41^s$ A.M., latitude 50° 21′ N., longitude 23° 56′ W., sun's magnetic azimuth S. ½ W., observed altitude sun's L.L. 12° 19′ 0″, index error — 3′ 20″, height of eye 21 feet: required the true azimuth and error of the compass; and supposing the variation to be 33° 20′ W.: required the deviation of the compass for the position of the ship's head at the time the observation was taken.

11. 1887, May 29th, A.M. at ship, latitude by account 0° 31′ S., longitude 150° 40′ W., the observed altitude of the sun's L.L., North of the observer, was 67° 41′ 0″, index error + 1′ 0″, height of eye 20 feet, time by watch May $29^d\ 3^h\ 32^m\ 0^s$, which had been found to be $3^h\ 38^m\ 0^s$ *fast* on apparent time at ship, the difference of longitude made to the East since the error of watch on apparent time at ship was determined was 26·9 miles: required the latitude by reduction to meridian.

12. 1887, November 17th, A.M. at ship, and uncertain of my position, when a chronometer showed November $17^d\ 5^h\ 44^m\ 12^s$ M.T.G., observed altitude sun's U.L. 17° 21′ 40″; again, P.M. at ship same day, when chronometer showed November $17^d\ 11^h\ 15^m\ 36^s$, observed altitude sun's U.L. 12° 41′ 20″, height of eye 17 feet, the ship having made 27 miles on a true E. ¾ S. course in the interval: required the line of bearing when the first altitude was taken, and the ship's position by Sumner's Method when the second altitude was observed, assuming the ship to be between the latitudes 45° 55′ N., and 46° 15′ N.

CHART WORK FOR ONLY AND FIRST MATES.

Outline English Channel Chart (True). Var. 21½° W.

I. Using Deviation Card No. I, find the course to steer by compass from Seven Stones lightvessel to Lundy Island, also the distance.

II. With the ship's head on the above-named compass course Longships light bore by compass E.N.E., and Trevose Head bore S.E. by E. ¾ E. by the same compass: find the ship's position.

III. With the ship's head as above Trevose Head bore by compass S.E. by E., and after continuing on the same course 23 miles it bore S.S.W. ¼ W.: find the position of the ship, and her distance from Trevose Head at the time of taking the second observation.

ADDITIONAL FOR MASTER.

IV. Find the course to steer by compass from Seven Stones to Lundy Island (or from A to B) (see Question I) to counteract the effect of a current which set N. by W. ½ W. (true) at the rate of 4½ miles an hour, the ship making by log 20 miles in the 2 hours towards Lundy Island.

V. 1885, May 22nd, $8^h\ 21^m$ P.M., being off Caldy Island by reckoning, took a cast of the lead: required the correction to be applied to the depth obtained by the lead line before comparing it with the depth marked on the chart.

13. 1887, June 17th, the obs. mer. alt. of star α Serpentis, North of observer, was 29° 0′ 40″, index correction + 4′ 20″, height of eye 24 feet: required the latitude.

In the following table give the correct magnetic bearing of the distant object, and thence the deviation :—

Correct magnetic bearing.

Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.	Ship's Head by Standard Compass.	Bearing of Distant Object by Standard Compass.	Deviation Required.
North	N. 40° W.		South	S. 41° W.	
N.E.	W. 10 N.		S.W.	W. 16 S.	
East......	W. 18 S.		West	N. 67 W.	
S.E.......	S. 36 W.		N.W.	N. 36 W.	

With the deviation as above, give the courses you would steer by the Standard Compass to make the following courses correct magnetic.

Correct magnetic courses :—S. 10° W.; N.W. ¼ N.; E. by S.; N. by E. ½ E.

Compass courses :—

Supposing you have steered the following courses by the Standard Compass, find the correct magnetic courses made from the above deviation table.

Compass courses :—N. ¼ E.; S.E. ½ S.; W. by N. ¼ N.; South.

Magnetic courses :—

You have taken the following bearings of two distant objects by your Standard Compass as above, with the ship's head at S. ½ E., find the bearings, correct magnetic.

Compass bearings :—E. ¼ N., and N. by W. ½ W.

Bearings, magnetic :—

ANSWERS.

CHARACTERISTICS OF LOGARITHMS.

1. *Of a Number greater than unity, Page 20.*

1. 2
2. 6
3. 2
4. 1
5. 0
6. 4
7. 1
8. 3
9. 1
10. 0
11. 5
12. 3
13. 0
14. 0
15. 1
16. 2
17. 7
18. 4
19. 0
20. 1

2. *Of Decimals, Page 21.*

1. $\bar{2}$ or 8
2. $\bar{1}$ or 9
3. $\bar{4}$ or 6
4. $\bar{1}$ or 9
5. $\bar{3}$ or 7
6. $\bar{7}$ or 3
7. 2 or 8
8. $\bar{4}$ or 6
9. $\bar{2}$ or 8
10. $\bar{1}$ or 9
11. $\bar{1}$ or 9
12. $\bar{3}$ or 7
13. $\bar{7}$ or 3
14. $\bar{5}$ or 5
15. $\bar{4}$ or 6
16. $\bar{2}$ or 8
17. $\bar{7}$ or 3
18. $\bar{7}$ or 3
19. $\bar{1}$ or 9
20. $\overline{11}$ or 9

LOGARITHMS OF NATURAL NUMBERS.

1. *Numbers consisting of not more than two digits, Page 24.*

1. 0·698970
2. 0·954243
3. $\bar{3}$·954243 or 7·954243
4. $\bar{2}$·000000 or 8·000000
5. $\bar{4}$·000000 or 6·000000
6. 1·146128
7. 1·612784
8. $\bar{3}$·602060 or 7·602060
9. 0·380211
10. 1·380211
11. $\bar{1}$·380211 or 9·380211
12. $\bar{3}$·322219 or 7·322219
13. 1·973128
14. $\bar{1}$·698970 or 9·698970
15. $\bar{1}$·875061 or 9·875061
16. 0·397940
17. $\bar{1}$·397940 or 9·397940
18. $\bar{2}$·954243 or 8·954243
19. $\bar{3}$·959041 or 7·959041
20. 1·397940
21. $\bar{2}$·380211 or 8·380211
22. $\bar{5}$·544068 or 5·544068
23. $\bar{5}$·755875 or 5·755875
24. $\bar{4}$·698970 or 6·698970

2. *Numbers consisting of not more than three places of figures, Page 24.*

1. 2·000000
2. 2·161368
3. 0·468347
4. 2·557507
5. 2·828015
6. 2·899820
7. 2·992111
8. 0·681241
9. 0·952308
10. 0·167317
11. $\bar{1}$·167317 or 9·167317
12. $\bar{1}$·954725 or 9·954725
13. $\bar{2}$·167317 or 8·167317
14. 2·627366
15. $\bar{5}$·651278 or 5·651278
16. 5·651278

3. *The Number containing four places of figures, Page 25.*

1. 3·000000
2. 3·091315
3. 1·409087
4. 3·734960
5. 1·415974
6. 0·415974
7. $\bar{2}$·005180 or 8·005180
8. 1·977129
9. 0·890812
10. 2·994581
11. $\bar{2}$·835247 or 8·835247
12. $\bar{3}$·444669 or 7·444669

4. *The Number consisting of more than four figures, Page* 26.

1. 4·585178
2. 2·585178
3. 4·091491
4. 2·734968
5. 4·823904
6. 3·965898
7. 2·639088
8. 1·895445
9. 0·343507
10. $\bar{1}$·894105 or 9·894105
11. 4·000000
12. $\bar{4}$·903129 or 6·903129
13. 5·301030
14. $\bar{2}$·749845 or 8·749845
15. $\bar{3}$·993714 or 7·993714
16. 5·808742
17. 3·052717
18. $\bar{1}$·999172 or 9·999172
19. 5·562474
20. 2·998755
21. 1·507732
22. 0·014001
23. 3·000003
24. 2·775555

NATURAL NUMBER OF LOGARITHMS, *Page* 29.

1. 3
2. 1·10
3. 9·4
4. 14·5
5. 6·49
6. 586
7. 2·48
8. 30·09
9. 7916
10. 345·6
11. 24·83
12. 7000
13. 10000000
14. 669000
15. 50000
16. 100000
17. 978·5
18. 34800
19. ·5547
20. ·3171
21. ·00000075
22. 4000000
23. ·00000007
24. 4029
25. ·0000009797
26. 80080000
27. ·04183
28. ·000000007968
29. ·0046
30. ·00071
31. 8199000
32. 738800

Page 30.

1. 853·52157
2. 4220·3
3. 71106
4. 23000·1
5. 53·133
6. 93·8689
7. 543210
8. 666660
9. 98765
10. 84321
11. 123456
12. 342·945
13. 678945·3
14. 69500·645
15. 12375·426
16. 16·51374
17. ·0096532
18. ·000290888
19. ·0174533
20. 2349632·4
21. ·0000017645
22. ·99727
23. ·000856735
24. ·000036808

LOGARITHMS OF NATURAL NUMBERS, *Page* 30.

1. 0·903090
2. $\bar{1}$·000000
3. 0·690196
4. 1·579784
5. 2·579784
6. 2·000000
7. 6·000000
8. 1·390935
9. 3·805501
10. $\bar{1}$·165244
11. 0·588160
12. 2·942504
13. $\bar{1}$·096910
14. $\bar{4}$·954243
15. 2·926548
16. 1·964240
17. 4·000000
18. 3·958124
19. $\bar{4}$·763428
20. $\bar{2}$.554755
21. $\bar{4}$·651278
22. 6·651278
23. 1·972043
24. 4·698970
25. 5·845154
26. 5·421604
27. 5·699759
28. 7·000000
29. 2·792392
30. 4·477134
31. 7·947385
32. 2·458852
33. $\bar{3}$·551938
34. $\bar{4}$·932847
35. 7·816109

NATURAL NUMBERS OF LOGARITHMS, *Page* 30.

1. 204
2. 4753
3. 9
4. 50
5. 1
6. 100
7. 366·855
8. 3659
9. 3·673
10. 594500
11. 1000
12. 2480000
13. 26·042
14. ·09
15. ·0091
16. 2·606
17. ·1
18. ·009
19. ·052
20. 2·71828
21. 404007·5
22. 100000
23. ·0762
24. ·147
25. ·00000075
26. 1·00043
27. 8859000
28. ·0918504
29. ·763888
30. 4220·3
31. 53·1329
32. ·042404
33. ·0048553
34. ·000209675
35. 7·5

MULTIPLICATION BY LOGARITHMS, *Page* 33.

1. 3·774517 = 5950; 3·000000 = 1000; 3·521269 = 3321; 4·425758 = 26653·7.
2. 2·971331 = 936·12; 4·034147 = 10818; 3·494850 = 3125; 4·443232 = 27748.
3. 1·009026 = 10·21; 0·436878 = 2·7345; $\bar{1}$·818753 = ·6588; 1·575742 = 37·648.
4. 4·532375 = 34070·2; 2·639870 = 436·385; 1·292881 = 19·62826; 6·783260 = 6071000.
5. 7·146212 = 14002718; 6·445142 = 2787032; 6.919110 = 8300615; 7·498480 = 31512319.

6. 7·499467 = 31583985·5; 3·782115 = 6055; 3·842614 = 6960·08; 4·327379 = 21250·98.
7. 5·599311 = 397476·1; 3·590806 = 3897·68; 5·477728 = 300419·31; 7·623683 = 42041942.
8. 6·314887 = 2064842·8; 2·552762 = 357·077; 3·983651 = 9630·555.
9. 3·394677 = 2481·28; 4·312842 = 20551·4; 0·123363 = 1·32850; 3·519872 = 3310·34.
10. $\bar{8}$·763323 = ·000000057986; $\bar{3}$·778168 = ·006000236; $\bar{7}$·740796 = ·00000055055.
11. 2·951043 = 893·394; 3·398070 = ·00250075; $\bar{4}$·783623 = ·000607607.
12. $\bar{2}$·00000 = ·01; $\bar{1}$·000000 = ·000000001; $\bar{5}$·050035 = ·0000112211; 5·000000 = 100000.

DIVISION BY LOGARITHMS, *Page* 36.

1. 1·919078 = 83; 2·778875 = 601; 2·096910 = 125; 2·644712 = 441·28.
2. 4·986680 = 96979·5; 3·698970 = 5000; 5·880170 = 758875·4; 1·775257 = 59·6015.
3. 0·494768 = 3·1244; 1·614317 = 41·145; 1·428589 = 26·828.
4. 0·472427 = 2·967748; $\bar{2}$·785908 = ·06108; $\bar{2}$·385683 = ·0243043; $\bar{5}$·301030 = ·00002; $\bar{4}$·301030 = ·0002; 1·301030 = 20.
5. 3·886534 = 7700·76 +; $\bar{1}$·999234 = ·998236; 1·999489 = 99·8825.
6. 1·995636 = 99; 2·319142 = 208·517; 1·854294 = 71·498; 0·793259 = 6·2124.
7. 4·699490 = 50060; 4·514747 = 32715; 4·317415 = 20769; 2·096910 = 125.
8. $\bar{1}$·832752 = ·68038; 4·903504 = .000800763; $\bar{1}$·030734 = ·107333; 3·509203 = 3230.
9. $\bar{1}$·421422 = ·263889; 1·421422 = 26·3889; $\bar{1}$·421422 = ·263889; 3·421422 = 2638·89; 7·301030 = 20000000; 7·477122 = 30000000.
10. 2·339894 = 218·723; 2·934196 = 859·4; $\bar{1}$·004751 = ·1011; 7·505150 = 32000000; $\bar{5}$·028878 = ·0000106875.
11. 0· = 1; 13· = 10000000000000; $\bar{1}$· = ·1; $\bar{2}$· = ·01; 4· = 10000.

NATURAL SINES AND COSINES, *Page* 47.

Natural Sines.

1.	570774	2.	867085	3.	370382	4.	997630

Natural Cosines, Page 47.

1.	167237	2.	995612	3.	688000	4.	989472

Arcs of Natural Sines, Page 48.

1.	63° 53′ 47″	2.	53° 7′ 49′	3.	26° 21′ 34″
4.	11 45 52	5.	31 57 10	6.	73 44 23

Arcs of Natural Cosines, Page 48.

1.	63° 19′ 58″	2.	18° 29′ 12″	3.	59° 0′ 47″
4.	12 53 4	5.	2 33 48	6.	53 7 48

LOG. SINES, TANGENTS, SECANTS, ETC., *Page* 50.

1.	9·202234	4.	9·883934	7.	9·774729	10.	9·275658
2.	10·185981	5.	10·829843	8.	9·895443	11.	10·144904
3.	9·989071	6.	10·135990	9.	10·308556	12.	10·137677

Page 56.

NO.	SINE.	TANGENT.	SECANT.	COSINE.	COTANGENT.	COSECANT.
1.	9·787595	9·890004	10·102409	9·897591	10·109996	10·212405
2.	9·923122	10·185903	10·262781	9·737219	9·814097	10·076878
3.	9·246845	9·253720	10·006876	9·993124	10·746280	10·753155
4.	8·504189	8·504410	0·000221	9·999779	11·495590	11·495811
5.	9·999580	11·356298	11·356719	8·643281	8·643702	10·000421
6.	8·246654	8·246721	10·000068	9·999932	11·753279	11·753346

7.	8·668140	11.	8·361681	15.	10·348195	19.	8·024643	23.	10·714152
8.	9·217232	12.	9·505271	16.	10·100598	20.	8·658227	24.	9·972464
9.	8·504188	13.	8·297036	17.	10·203770	21.	8·305785		
10.	6·298326	14.	11·263695	18.	8·346002	22.	8·258261		

ARCS OF LOG. SINES, *Page* 58.

1.	33° 26′ 48″	3.	2° 55′ 26″	5.	18° 26′ 6″	7.	0° 9′ 50″	9.	52° 35′ 30″
2.	57 30 53	4.	2 17 7	6.	54 13 20	8.	87 38 20	10.	1 39 39

ARCS OF LOG. COSINES, *Page* 58.

1.	52° 13′ 35″	3.	81° 18′ 0″	5.	88° 40′ 54″	7.	3° 56′ 40″	9.	89° 38′ 20″
2.	89 13 8	4.	70 47 25	6.	31 9 33	8.	88 54 17	10.	84 15 39

ARCS OF LOG. SECANTS, *Page* 58.

1.	3° 24′ 0″	2.	51° 28′ 50″	3.	26° 33′ 0″	4.	18° 22′ 17″	5.	88° 41′ 42″

ARCS OF LOG. COSECANTS, *Page* 58.

1.	34° 1′ 14″	3.	49° 11′ 9″	5.	1° 57′ 4″	7.	58° 15′ 30″	9.	78° 22′ 32″
2.	5 40 13	4.	2 4 7	6.	3 54 45	8.	4 46 56	10.	2 56 20

ARCS OF LOG. TANGENT, *Page* 58.

1.	45° 0′ 24″	3.	5° 13′ 23″	5.	1° 8′ 7″	7.	87° 0′ 46″	9.	2° 40′ 10″
2.	62 42 21	4.	86 58 16	6.	27 28 54	8.	48 58 24	10.	1 2 18

ARCS OF LOG. COTANGENTS, *Page* 58.

1.	3° 37′ 50″	2.	88° 46′ 54″	3.	88° 55′ 35″	4.	88° 20′ 53″	5.	0° 29′ 16″

MISCELLANEOUS EXAMPLES.

For practice in natural and logarithmic Sines, Tangents, and Secants, *Page* 58.

1. Nat. sine ·432651, its common log. is 9·636138, which is the log. sine required.

2. Nat. tang. 3, its common log. is 10·477121, which is the log. tang. required.

3. Log. 9·236713, its corresponding nat. no. is ·172470, the nat. cos. required.

4. The given log. tang. 9·850593, being subtracted from 20, gives 10·149407, the log. cotang.

5. The nat. sine of 68° 45′ 24″ is ·932050, the log. of which, or 9·969439, is its log. sine, which, being subtracted from 20, leaves 10·030561 for the log. cosec.

6. The log. sec. 11·024680 subtracted from 20 leaves 8·975320, the log. cosine, the nat. no. corresponding to which, or ·094476, is the nat. cosine sought.

7. 1. The quantity 9·450981 is found in the tables to be the log. cosine of the arc 73° 35′ 31″. 2. The nat. no. corresponding to the given log. is ·282476, which is the nat. cos. of 73° 35′ 31″, the arc A sought.

8. 1. The square of radius, or 1, divided by the nat. sec. 2·005263, gives ·498688, the nat. cosine of A, which is found in the tables of nat. cosines to correspond to 60° 5′ 12″, the value A. 2. The common log. of the nat. sec. 2·005263 is 0·302171, which is found to be the log. sec. of 60° 5′ 12″, the arc A sought.

Note.—A natural sine can be taken out of a table of nat. versines with the most minute accuracy.

$$\begin{aligned} \text{Versine } (90+\theta) &= 1 - \text{cos. } (90+\theta) \\ &= 1 + \text{sine } \theta \\ \therefore \text{Sine } \theta &= \text{versine } (90+\theta) - 1 \end{aligned}$$

Or the natural sine of an angle is taken out of the table of versines, by taking out the versine of the angle *increased* by 90°, and dropping the initial 1.

DIFFERENCE OF LATITUDE, *Page* 79.

1.	203′ N.	3.	293′ S.	5.	795′ N.	7.	610′ S.	9.	94′ N.
2.	470 S.	4.	330 N.	6.	157 S.	8.	459 N.		

MERIDIONAL DIFFERENCE OF LATITUDE, *Page* 80.

1.	97	2.	2426	3.	345	4.	1216	5.	932	6.	260

LATITUDE IN, *Page* 82.

1. 34° 2′ N.
2. 27 54 N.
3. 3° 1′ N.
4. 2 48 S.
5. 2° 54′ S.
6. Equator.
7. Equator.
8. 39° 14′ S.

MIDDLE LATITUDE, *Page* 82.

1. 17° 19′
2. 2° 10½′
3. 35° 37′
4. 61° 31½′
5. 53° 12½′
6. 64° 31′

DIFFERENCE OF LONGITUDE, *Page* 84.

1. 300′ E.
2. 507 E.
3. 716′ W.
4. 260 W.
5. 270′ E.
6. 422 W.
7. 368′ E.
8. 420 W.
9. 180′ W.
10. 412 E.
11. 2835′ E.
12. 1200 W.

LONGITUDE IN, *Page* 85.

1. 7° 38′ W.
2. 1° 18′ E.
3. 31° 4′ E.
4. 0° 30′ W.
5. 1 15 E.
6. 0 45 W.
7. 39 10 W.
8. 92 9 E.
9. 103 56 E.
10. 178 26 W.
11. 178 57 E.
12. 179 59 E.

LEEWAY—CORRECTED COURSES, *Page* 96.

1. S.W. ½ S.
2. S.S.W. ¼ W.
3. N. ¼ E.
4. N.E. ½ E.
5. E. by S.
6. N.W. by W.
7. W. ½ S.
8. N.E. by E. ¾ E.

DEVIATION—CORRECT MAGNETIC COURSES, *Page* 104.

1. S. 10° 2′ W.
2. N. 9° 41′ E.
3. S. 59° 23′ W.
4. S. 22° 34′ E.
5. S. 5 56 E.
6. N. 38 45 E.
7. S. 47 30 E.
8. S. 87 22 W.

LEEWAY, VARIATION, & DEVIATION—TRUE COURSES, *Page* 106.

1. South.
2. S. 44° 15′ E.
3. N. 77 45 W.
4. S. 85 7 E.
5. S. 78 41 W.
6. S. 5 34 E.
7. S. 73 26 W.
8. S. 31 26 W.
9. S. 57 30 W.
10. S. 76 56 E.
11. N. 84 23 W.
12. S. 81° 15′ E.
13. S. 31 53 W.
14. S. 35 56 E.
15. S. 8 45 E.
16. N. 59 11 E.
17. N. 88 46 E.
18. S. 60 8 W.
19. N. 9 45 E.
20. S. 60 30 E.
21. S. 76 19 W.
22. N. 10 34 W.
23. S. 19° 26′ E.
24. S. 89 45 W.
25. S. 0 4 E.
26. S. 0 8 E.
27. S. 15 15 W.
28. S. 4 41 E.
29. N. 77 26 E.
30. N. 51 19 E.
31. N. 42 37 E.
32. S. 14 26 W.
33. S. 24 49 W.
34. East.

DIFFERENCE OF LATITUDE AND DEPARTURE, *Page* 114.

No.	Diff. lat.	Dep.	No.	Diff. lat.	Dep.
1.	27′·7 S.	11′·5 E.	8.	10′·8 S.	33′·3 W.
2.	9·4 S.	47·1 E.	9.	22·9 N.	8·8 W.
3.	100·8 S.	91·3 W.	10.	10·9 S.	23·3 W.
4.	12·3 N.	83·1 W.	11.	2·5 S.	14·5 W.
5.	21·8 S.	48·0 E.	12.	27·3 N.	13·9 W.
6.	142·7 S.	173·9 W.	13.	7·4 S.	42·2 W.
7.	44·5 N.	177·5 E.	14.	33·2 N.	10·8 W.

COURSES AND DISTANCES, *Page* 115.

NO.	COURSE.	DIST.	NO.	COURSE.	DIST.
1.	S. 19° E.	77′	6.	N. 44° E.	52½′
2.	N. 67 E.	186½	7.	S. 55 W.	93
3.	N. 66½ W.	161	8.	S. 6 W.	161½
4.	S. 21 E.	105½	9.	S. 2½ W.	173
5.	N. 30 W.	480	10.	N. 58 E.	310

TRAVERSE SAILING, *Page* 120.

Note.—In the following key the first line for each question is explained by the titles at the top of the page. The second line contains the courses and distances sailed. The third line contains the D. Lat. and Dep. corresponding to each course and distance; their names are not given because they are easily seen from the course in the second column.

Note.—In question 3 below, 375·8 N. means 375·8 by Norie, and 375·6 R. means 375·6 by Raper.

	Courses.	Distance.	Diff. Lat.	Departure.	Lat. in.			
1	S 44° W	132'	95'·2 S	92'·1 W	51° 23' N.			
	N 7 W 44' 8'·6 43'·2	S 1 E 45' 44'·1 8'·8	S 7 W 35' 6'·8 34'·3	S 2 E 44' 40'·7 16'·8	S 6½ W 42' 12'·2 40'·2			
2	S 81° W	130'	20'·0 S	128'·8 W	53° 52' N			
	S 6 W 12' 4'·6 11'·1	N 4 W 24' 17'·0 17'·0	S 1 W 20' 19'·6 3'·9	N 5 W 32' 17'·8 26'·6	S 1 E 36' 35'·3 7'·0	N 6½ W 42' 12'·2 40'·2	S 2½ E 16' 14'·1 7'·5	N 7¼ W 45' 6'·6 44'·5
3	South.	375'·8 (N) 375'·6 (R)	375'·8 S (N) 375'·6 S (R)	0	2° 26' S			
	S 2 W 112' 103'·5 42'·9	S 1 E 86' 84'·4 16'·8	S. 2 E 112' 103'·5 42'·9	S 1 W 86' 84'·4 16'·8				
4	East	77'	0'·0	76'·8 E	19° 0' S.			
	S 3½ E 13' 10'·0 8'·2	S 1 E 19' 18'·6 3'·7	S 5 E 22' 12'·2 18'·3	S 6¾ E 32' 7'·8 31'·0	N 2 E 20' 18'·5 7'·7	N 1¼ W 27' 26'·2 6'·6	N 5½ E 24' 11'·3 21'·2	S 3¾ W 10' 7'·4 6'·7
5	S. 46° E.	109'	75'·2 S	78'·3 E	0° 15' S			
	East 8' 8'·0	N 7¾ E 20' 1'·0 20'·0	S. 5 E. 33' 18'·3 27'·4	S ¾ W 31' 30'·7 4'·6	N 3½ E 43' 33'·2 27'·3	South 28' 28'·0	S ¾ E 21' 20'·8 3'·1	S 1¼ W 12' 11'·6 2'·9
6	S 24° W	88'	80'·4 S	36'·0 W	0° 10' S			
	N 40° W 20' 15'·3 12'·9	S 56° W 51' 28'·5 42'·3	S 19° W 19' 18'·0 6'·2	S 48° W 16' 10'·7 11'·9	N 85° E 28' 2'·4 27'·9	S 44° E 15' 10'·8 10'·4	N 22 W 25' 23'·2 9'·4	S 9° E 54' 53'·3 3'·4
7	S 15° W	32'	31'·0 S	8'·4 W	46° 41' N.			
	S 31° W. 16' 13'·7 8'·2	N 72° E 13'·1 4'·1 12'·5	S 52° W 15' 9'·2 11'·8	S 44° E 15'·1 10'·9 10'·5	N 44° W 19'·7 14'·2 13'·7	N 77° E 11'·4 2'·6 11'·1	S 40° W 16' 12'·3 10'·3	S 14° E. 6' 5'·8 1'·5
8	N 80° W	147'	24'·7 N	145'·1 W	34° 36' N			
	N 36° W 27' 21'·8 15'·9	N 24° E 30' 27'·4 12'·2	S 75° W 47' 12'·2 45'·4	S 80° W 29' 5'·0 28'·6	N 72° W 42' 13'·0 39'·9	N 78° W 34' 7'·1 33'·3	S 12° E 28' 27'·4 5'·8	
9	N 66° W	140'	55'·7 N	127'·9 W	35° 39' S			
	N 84° W 18' 1'·9 17'·9	N 89° W 30'·4 0'·5 30'·4	N 67° W 29'·9 11'·7 27'·5	N 39° W 33'·9 26'·3 21'·3	N 8° W 25'·9 25'·7 3'·6	N 73° W 34'·9 10'·2 33'·4	N 86° W 44'·7 3'·1 44'·6	S 65° E 56' 23'·7 50'·8

PARALLEL SAILING, *Page* 125.

1. D. Long. 400 miles, or 6° 40'. 2. 7° 9'.
3. The parallel of 60°. 4. Length of a degree 20·52 miles.
5. In lat. 60° North or South. 6. Dep. 344·1 miles.
7. The former vessel, and will gain 149 miles. 8. 593·4 miles.
9. 60° and 70° 32'. 10. 61·6 miles, or 1° 1'·6.
11. West, distance 864·1 miles. 12. 75° 30'. 13. 102·6 miles.

MIDDLE LATITUDE SAILING, *Page* 130.

1. D. lat. 113'·3 Dep. 273'·5 Lat. in 27° 28' N. D. long. 305' Long. in 54° 55' W.
2. „ 165·6 „ 223·3 „ 49 0 N. „ 334 „ 178 58 W.
3. „ 96·7 „ 318·7 „ 18 52 N. „ 338 „ 175 12 E.
4. Dep. 2439 miles; Course S. 84° 50' 15" W.; Dist. 2450 miles.
5. True course N. 61° 53' E., distance 2101 miles.
6. True course N. 80° 2' 30" E., distance 2018 miles.

MERCATOR'S SAILING, *Page* 135.

NO.	D. LAT.	M. D. LAT.	D. LONG.	LOG. TANG.	COURSE.	LOG. DIST.	DIST.
1.	97 N.	125	131 E.	10·020381	N. 46° 21' E.	2·147765	141'
2.	85 S.	130	76 E.	9·766871	S. 30 19 E.	1·993283	98·5
3.	230 S.	500	270 E.	9·732394	S. 28 22 E.	2·417282	261·4
4.	1232 N.	1760	4732 E.	10·429532	N. 69 36 E.	3·548318	3534
5.	115 N.	166	191 E.	10·060925	N. 49 0 E.	2·243755	175·3
6.	792 S.	794	1254 E.	10·198477	S. 57 39½ E.	3·170398	1480
7.	2937 N.	3162	7919 E.	10·398708	N. 68 14 E.	3·898732	7920
8.	4875 S.	8836	4875 W.	9·741719	S. 28 53 W.	3·745667	5568
9.	1011 N.	1139	3808 W.	10·524173	N. 73 21 W.	3·547589	3528
10.	5669 N.	6510	2490 E.	9·582618	N. 20 56 E.	3·783161	6070
11.	731 S.	733	2459 E.	10·525655	S. 73 24 E.	3·408024	2559
12.	5545 S.	6323	262 E.	8·617378	S. 2 22 E.	3·744273	5550
13.	4483 N.	4842	3313 E.	9·835196	N. 34 23 E.	3·734969	5432
14.	1860 S.	1884	412 E.	9·339816	S. 12 20 E.	3·279653	1904
15.	3355 N.	3516	7587 W.	10·334021	N. 65 8 W.	3·901919	7978·5
16.	180 N.	190	1140 W.	10·778151	N. 80 32 W.	3·039176	1094·5

DAY'S WORKS CORRECTED FOR LEEWAY, VARIATION, AND DEVIATION, *Pages* 149-154.

Note.—In the following key, the first line for each day's work is explained by the titles at the top of the page. The second line contains the True Courses and Distances. The third line contains the Diff. Lat. and Dep. corresponding to each course and distance; their names are not given because these are easily seen from the courses in the second line.

1	Courses.	Distance.	Diff. Lat.	Departure.	Lat. in.	Mid. Lat.	Diff. Long.	Long. in.
	N 63° E	227'	102'·2 N.	202'·8 E	36° 57' N.	36° 6'	251' E	71° 19' W.
	N 89° E 19' 0'·3 19'·0	S 43° E 50' 36'·6 34'·1	S 71 E 38' 12'·4 35'·9	N 55° E 42' 24'·1 34'·4	N 3° W 42' 41'·9 2'·2	N 15° E 42' 40'·6 10'·9	N 82° E 37' 5'·1 36'·6	N 41° E 52' 39'·2 34'·1
2	S 77½° E	99'	21'·5 S	96'·6 E	53° 45½' N	53° 56'	164' E	2' 39 E
	S 68° E 17' 6'·4 15'·8 N 3° W 6' 6'·0 0'·3	N 73° E 28' 8'·2 26'·8	S 75° E 31' 8'·0 29'·9	N 72° E 20' 6'·2 19'·0	S 9° W 19' 18'·8 3'·0	S. 5° W 13' 13'·0 1'·1	S 20° E 10' 9'·4 3'·4	N 24° E 15' 13'·7 6'·1
3	North	86'·6	86'·6 N		45° 14' N			7° 51' W
	N 17° E 13' 12'·4 3'·8	North 38' 38'·0	N 27° E 18' 16'·0 8'·2	N 79° E 25' 4'·8 24'·5	S 83° W 23' 2'·8 22'·8	S 48° E 25'·2 16'·9 18'·7	N 48° W 27'·1 18'·1 20'·1	N 36° W 21' 17'·0 12'·3
4	N 75° W	70'	21'·1 N	76'·3 W	45° 51' S	46° 1'	110' W	1° 45' W
	N 50° W 20' 12'·9 15'·3	S 73 W 26' 7'·6 24'·9	N 40° E 34' 26'·0 21'·9	S 54° E 22' 11'·9 17'·8	N 67 W 25' 9'·8 23'·0	N 67° E 26' 10'·2 23'·9	S 44° W 24' 17'·3 16'·7	West 60' 60'·0
5	S 45° W	82'	58'·3 S	58'·1 W	34° 12' N	34° 41'	71' W	6° 47' W
	S 87° W 9' 0'·5 9'·0	S 29 W 38' 33'·2 18'·4	N 23° W 45' 41'·4 17'·6	N 77° W 34 7'·6 33'·1	South 46' 46'·0	S 29° W 37'·5 32'·8 18'·2	N 71° E 24'·[illegible] 8'·1 23'·5	S 79° E 15' 2'·9 14'·7
6	N 3° W	28'·5	28'·5 N	1'·6 W.	30° 27'·5 N	30° 13'	2' W	32° 52' E
	S 3° E 15' 15'·0 0'·8	N 75° W 12' 3'·1 11'·6	S 63° E 13' 5'·9 11'·8	S 10° E 25' 24'·6 4'·3	N 8° E 20' 19'·8 2'·8	S 76° W 15' 3'·6 14'·6	N 11° W 27' 26'·5 5'·2	N 20° E 30' 28'·2 10'·3
7	S 50° W	87'	56'·5 S	66'·5 W	45° 16½' S	44° 48'	94' W	179° 30' E
	N 70° W 18' 6'·2 16'·9	N 20° E 38' 35'·7 13'·0	N 88° W 34' 1'·2 34'·0	S 83° W 48' 5'·8 47'·6	S 9° W 25' 24'·7 3'·9	S 2° W 38' 38'·0 1'·3	S 19° E 50' 47'·3 16'·3	N 26° E 18' 16'·2 7'·9
8	N 70° E	161'	55'·3 N	151'·2 E	63° 13' N	62° 45'	330' E	57° 47' W
	N 66° E 21' 8'·5 19'·2	N 71° E 50' 16'·3 47'·3	N 75° E 17' 4'·4 16'·4	N 35° E 34' 27'·9 19'·5	S 28° W 14' 12'·4 6'·6	S 74° E 21' 5'·8 20'·2	S 2° W 17' 17'·0 0'·6	N 47° E 49' 33'·4 35'·8

	Courses.	Distance.	Diff. Lat.	Departure.	Lat. in.	Mid. Lat.	Diff. Long.	Long. in.
9	N 84° E	94½'	9'·1 N	94'·0 E.	70° 41' N	70° 35½'	283' E	19° 11' W
	S 34° E 23' 19'·1 12'·9	S 59' E 19' 9'·8 16'·3	N 33° W 25' 21'·0 13'·6	S 8° W 22' 21'·8 3'·1	N 3° E 33' 33'·0 1'·7	S 24° W 19' 17'·4 7'·7	N 65° E 25' 10'·6 22'·7	N 79° E 65' 12'·6 64'·8
10	N 78° E	214'	45'·1 N	209'·2 E	36° 57' S	37° 19½'	263'	177° 1' E
	S 78° E 21' 4'·4 20'·5	N 9° E 48' 47'·4 7'·5	N 72° E 42' 13'·0 39'·9	S 50' E 48' 30'·9 36'·8	S 8° E 35' 34'·7 4'·9	N 32° E 35' 29'·7 18'·5	N 75° E 49' 12'·7 47'·3	N 70° E 36' 12'·3 33'·8
11	S 88° E	334'	11'·4 S	333'·3 E	32° 53' S	32° 47½'	395'·5 E	2° 16'·5 E
	East 27' 27'·0	N 87° E 43' 2'·3 42'·9	N 85° E 41' 3'·6 40'·8	East 50' 50'·0	S 63° E 29' 13'·2 25'·8	N 89° E 71' 1'·2 71'·0	S 88° E 38' 1'·3 38'·0	S 84° E 38' 4'·0 37'·8
12	N 85° W	247'	15'·5 N	246'·1 W	44° 3½' S	44° 12'	343' W	177° 28' E
	West 16' 16'·0	N 62° W 40' 18'·8 35'·5	N 63° W 37' 16'·8 33'·0	S 86° W 38' 2'·7 37'·9	S 83° W 31' 3'·8 30'·8	S 50° W 31' 19'·9 23'·7	N 80° W 42' 7'·3 41'·4	West 28' 28'·0

ASTRONOMICAL DATES, *Page* 176.

1.	Jan.	$1^d 16^h 38^m 9^s$	5.	June	$30^d 23^h 30^m 10^s$
2.	Feb.	27 8 12 0	6.	Oct.	1 0 10 12
3.	Mar.	31 19 54 19	7. 1887.	Dec.	31 20 9 50
4.	July	1 8 3 24	8. 1888.	Dec.	31 12 44 12

CIVIL DATES, *Page* 176.

1.	Jan. 11th,	$4^h 31^m 15^s$ A.M.,	2.	Feb. 3rd,	$11^h 28^m 56^s$ P.M.
3.	May 17th,	7 15 11 P.M.,	4.	Mar. 14th,	11 15 7 A.M.
5.	Sept. 1st,	8 10 54 P.M.,	6.	Sept. 1st,	8 10 54 A.M.
7.	1888, Jan. 1st,	9 50 41 P.M.,	8.	1889, Jan. 1st,	10 41 56 A.M.

DEGREES INTO TIME, *Page* 177.

1.	$1^h 15^m 36^s$	$0^h 50^m 43^s$	$9^h 9^m 48^s$	$6^h 24^m 43^s$	$5^h 57^m 4^s$
2.	0 3 54·4	3 16 17·33	0 1 47·2	0 9 12·8	8 41 16
3.	0 0 54	3 24 40·8	10 27 28	11 55 19	0 2 46·8

TIME INTO DEGREES, *Page* 178.

1.	18° 28' 0"	2.	58° 1' 0"	3.	10° 33' 0"	4.	147° 24' 30"
5.	8 44 33	6.	5 22 43·5	7.	175 16 40	8.	0 58 0
9.	0 13 0	10.	75 12 45	11.	179 59 15	12.	0 28 0

GREENWICH DATES, *Page* 181.

1.	Jan.	$6^d 8^h 8^m 0^s$	5.	Oct.	$31^d 21^h 22^m 10^s$	9.	July	8 at noon
2.	Jan.	31 7 29 28	6.	Dec.	1 6 32 45	10.	Jan.	$31^d 13^h 45^m 20$
3.	Mar.	15 8 8 6	7.	June	30 16 36 52	11.	Mar.	2 0 5 40
4.	May	15 6 6 0	8.	Sept.	1 6 24 11	12. 1887.	Dec.	31 14 3 20

SUN'S DECLINATION, *Page* 187.

1.	22° 36' 41" S.	2.	16° 43' 49"·5 S.	3.	4° 4' 27"·5 N.	4.	19° 5' 36"·0 N.
5.	23 0 57 N.	6.	3 8 52 S.	7.	23 18 48 S.	8.	18 14 0 S.
9.	20 17 9 S.	10.	12 24 2 S.	11.	0 1 0 N.	12.	19 0 50 N.
13.	0 7 15 N.	14.	2 58 51 S.	15.	23 3 57 S.	16.	0 2 4 N.

EQUATION OF TIME, *Page* 191.

1.	$+\ 5^m 42^s{\cdot}1$	2.	$+\ 14^m 6^s{\cdot}6$	3.	$+\ 0^m 3^s{\cdot}8$	4.	$-\ 3^m 45^s{\cdot}1$
5.	+ 0 0·6	6.	+ 0 1·7	7.	− 0 1·1	8.	− 0 2·5
9.	+ 3 51·8	10.	+ 15 18·3	11.	− 0 7·5	12.	+ 0 5·8

TRUE ALTITUDES, *Page* 193.

Norie.

1.	17° 52' 42"	2.	48° 17' 14"	3.	76° 14' 16"	4.	58° 48' 29"
5.	65 13 4	6.	85 22 51	7.	27 51 38	8.	67 22 16

Raper.

1.	17° 52' 28"	2.	48° 17' 12"	3.	76° 14' 7"	4.	58° 48' 21"
5.	65 13 0	6.	85 22 45	7.	27 51 27	8.	67 22 7

MERIDIAN ALTITUDES, *Page* 197.

					RAPER'S	
NO.	GREEN. DATE.	RED. DECL.	TRUE ALT.	LATITUDE.	TRUE ALT.	LATITUDE.
1.	Jan. 10^d $3^h19^m24^s$	21°56′29″S.	68°57′22″	42°59′ 7″S.	68°57′18″	42°59′11″S.
2.	Jan. 31 21 20 36	17 7 46 S.	72 58 6	0 5 52 S.	72 58 3	0 5 49 S.
3.	April 28 11 1 32	14 16 56 N.	82 35 15	6 52 11 N.	82 35 9	6 52 5 N.
4.	May 1 21 51 48	15 20 17 N.	45 57 1	59 23 16 N.	45 56 56	59 23 21 N.
5.	June 10 19 48 12	23 4 37 N.	42 37 28	24 17 55 S.	42 37 24	24 17 59 S.
6.	Sept. 22 12 54 0	0 7 56 N.	41 42 33	48 25 23 N.	41 42 23	48 25 33 N.
7.	Oct. 23 6 0 48	11 29 0 S.	54 51 18	23 39 42 N.	54 51 11	23 39 49 N.
8.	Nov. 14 18 39 16	18 25 52 S.	67 56 49	3 37 19 N.	67 56 40	3 37 28 N.
9.	Mar. 20 11 54 0	0 1 42 N.	61 58 10	28 3 32 N.	61 58 1	28 3 41 N.
10.	April 7 9 19 0	6 57 45 N.	90 13 41	6 44 4 N.	90 13 40	6 44 5 N.
11.	Sept. 22 15 45 0	0 5 9 N.	83 52 20	6 12 49 N.	83 52 13	6 12 56 N.
12.	Nov. 2 16 56 0	14 58 5 S.	70 42 48	34 15 17 S.	70 42 44	34 15 21 S.
13.	Sept. 22 12 24 8	0 8 25 N.	71 34 38	18 33 47 N.	71 34 32	18 33 53 N.
14.	Feb. 12 0 32 48	13 40 57 S.	30 4 42	46 14 21 N.	30 4 35	46 14 28 N.
15.	Mar. 20 18 49 0	0 8 31 N.	77 7 26	12 44 3 S.	77 7 23	12 44 6 S.
16.	Dec. 31 15 37 52	23 3 32 S.	54 38 7	12 18 21 N.	54 38 6	12 18 22 N.

AMPLITUDES, *Page* 205.

No.	Green. date.	Red. decl.	True amp.	sine.	Error of Compass.	Deviation.
1.	Jan. $26^d19^h47^m8^s$	18°30′ 8″S.	E 23° 0′ S.	9·591875	33°15′ W	11°25′ W
2.	Feb. 17 4 7 28	11 55 19 S.	W 14 35½ S.	9·401267	19 9½ E	11 29½ E
3.	March 29 2 20 20	3 24 22 N.	E 3 47 N.	8·819889	26 17 W	2 37 W
4.	April 4 19 53 0	5 59 48 N.	W 6 24 N.	9·047177	0 16 W	6 56 W
5.	Nov. 6 22 5 8	16 15 15 S.	E 18 25½ S.	9·499690	21 14½ E	7 24½ E
6.	June 2 9 56 26	22 14 22 N.	W 38 27 N.	9·793480	26 14 W	11 6 E
7.	July 14 2 15 42	21 41 28 N.	E 24 59½ N.	9·625857	22 49½ E	11 9½ E
8.	Aug. 1 3 53 56	18 0 32 N.	E 37 6 N.	9·780447	54 24 E	32 44 E
9.	Sept. 7 21 37 0	5 45 43 N.	E 6 40 N.	9·042587	6 20 W	6 20 W
10.	Oct. 30 4 59 50	13 50 43 S.	E 24 10½ S.	9·612315	15 30½ E	13 19½ W
11.	Sept. 22 6 1 12	0 14 38 N.	E 0 26½ N.	7·885310	3 15½ W	14 15½ W
12.	Aug. 17 20 38 48	13 10 44 N.	W 27 7½ N.	9·658875	62 53½ W	26 3½ W
13.	March 20 10 11 4	0 0 0	0 0		0 0	15 0 W
14.	Sept. 22 21 2 8	0 0 0	0 0		0 0	21 50 E
15.	June 8 18 41 24	22 54 59 N.	E 22 55 N.		17 17½ W	2 57½ E
16.	Feb. 25 20 40 28	8 46 8 S.	E 19 0 S.	9·512597	48 30 W	12 45 W
17.	June 18 1 24 20	23 24 58 N.	E 64 36 N.	9·955851	39 23 E	24 28 E
18.	March 6 6 5 20	5 34 8 S.	W 6 31½ S.	9·055560	23 23½ W	5 33½ W
19.	April 9 18 50 48	7 51 18 N.	W 13 25½ N.	9·365821	21 51½ E	5 41½ E
20.	Dec. 13 11 35 26	23 11 38 S.	E 32 0 S.	9·724212	58 0 W	38 40 W

TIDES, *Page* 212.

1.	7^h30^mA.M.	8^h 5^mP.M.	16.	0^h17^mA.M.	0^h58^mP.M.
2.	8 43 „	9 4 „	17.	11 20 „	Midnight
3.	10 1 „	10 22 „	18.	No „	0 5 „
4.	No „	0 7 „	19.	No „	0 22 „
5.	0 26 „	0 44 „	20.	11 34 „	No „
6.	—— „	Noon „	21.	11 50 „	No „
7.	No „	0 8 „	22.	11 38 „	11 56 „
8.	0 8 „	0 32 „	23.	1 40 „	1 58 „
9.	—— „	Noon „	24.	0 6 „	0 44 „
10.	No „	0 15 „	25.	11 57 „	No „
11.	No „	0 27 „	26.	No „	0 27 „
12.	10 56 „	11 19 „	27.	10 29 „	10 59 „
13.	10 23 „	10 46 „	28.	11 56 „	No „
14.	—— „	Noon „	29.	No „	0 30 „
15.	11 7 „	11 52 „	30.	11 26 „	No „

TIDES—FOREIGN PORTS, *Page* 214.

1.	Constant + $6^h\ 3^m$	corr. for long. — 20^m	$0^h\ 4^m$A.M.	$0^h 22^m$P.M.
2.	Constant — 1 47	corr. for long. — 10	3 41 "	3 58 "
3.	Constant — 0 17	corr. for long. + 9	No "	0 10 "
4.	Constant — 3 41	corr. for long. + 18	No "	0 1 "
5.	Constant + 3 18	corr. for long. — 22	9 54 "	10 15 "
6.	Constant + 6 13	corr. for long. — 14	9 58 "	10 15 "
7.	Constant + 4 28	corr. for long. — 21	11 55 "	No "
8.	Constant + 2 13	corr. for long. — 18	0 53 "	1 30 "
9.	Constant — 0 17	corr. for long. — 20	10 55 "	11 27 "

FINDING DAILY RATE, *Page* 270.

1.	22 days	$3^s{\cdot}8$ *gaining*	6.	22 days	$1^s{\cdot}1$ *losing*
2.	18 "	3·0 *losing*	7.	15 "	6·0 *losing*
3.	17 "	4·5 *gaining*	8.	14 "	7·0 *gaining*
4.	15 "	11·2 *gaining*	9.	50 "	2·0 *losing*
5.	31 "	4·2 *losing*	10.	50 "	0·8 *gaining*

GREENWICH DATE, *Page* 273.

1.	$6^s{\cdot}8$ *losing*	$2^m45^s{\cdot}5$	Feb. 16^d $7^h47^m47^s{\cdot}5$	7.	$4^s{\cdot}8$ *gaining*	$7^m\ 5^s{\cdot}7$	Nov. 8^d $16^h26^m59^s{\cdot}7$
2.	7·1 *gaining*	4 2·7	April 28 4 21 37	8.	8·7 *losing*	6 57·6	Aug. 1 0 5 55·4
3.	3·22 *losing*	3 46·2	May 7 6 25 15	9.	1·0 *losing*	1 2·5	May 1 13 24 38·5
4.	2·2 *losing*	2 38·1	June 25 21 2 31	10.	0·8 *losing*	0 32·8	Jan. 20 0 4 56
5.	5·3 *gaining*	6 28·9	Oct. 25 8 34 43	11.	1·9 *losing*	4 29·2	Sept. 27 16 39 18
6.	4·0 *losing*	5 22	Jan. 19 12 33 28	12.	2·6 *gaining*	2 2·8	April 16 5 33 40

HOUR-ANGLE, *Page* 276.

1.	$4^h26^m34^s$	2.	$2^h50^m42^s$	3.	$4^h50^m20^s$	4.	$4^h\ 6^m56^s$
5.	4 8 45	6.	2 33 42	7.	4 3 50·2	8.	4 29 56

CHRONOMETER, *Pages* 284-286.

1. Interval 7 days, rate $9^s{\cdot}8$ *losing*, interval $25^d\ 19^h$, accumulated rate + $4^m\ 12^s{\cdot}7$, Green. date January $1^d\ 19^h\ 32^m\ 13^s{\cdot}3$, red. decl. 22° 56′ 28″ S., red. eq. T, *add* $4^m\ 9^s{\cdot}6$, true alt. 49° 19′ 18″, sum of logs. 9·158105, hour-angle $2^h\ 58^m\ 21^s$, M.T. ship January $1^d\ 21^h\ 5^m\ 49^s$. *Longitude* 23° 24′ 0″ E.

By *Raper:* True alt. 49° 19′ 13″, sine sq. 9·158140, hour-angle $2^h\ 58^m\ 22^s$. *Longitude* 23° 23′ 45″ E.

2. Interval 7 days, rate $7^s{\cdot}6$ *gaining*, interval $19^d\ 20^h$, accumulated rate — $2^m\ 30^s{\cdot}7$, Green. date February $18^d\ 19^h\ 45^m\ 57^s$, red. decl. 11° 20′ 31″ S., eq. T. $14^m\ 3^s{\cdot}9$ *add*, true alt. 21° 34′ 15″, sum of logs. 9·531862 hour-angle $4^h\ 45^m\ 50^s$, M.T. ship February $18^d\ 19^h\ 28^m\ 34^s$. *Longitude* 4° 20′ 45″ W.

By *Raper:* True alt. 21° 34′ 8″, log. sine sq. 9·531890, hour-angle $4^h\ 45^m\ 30^s$. *Longitude* 4° 20′ 45″ W.

3. Interval 43 days, rate $4^s{\cdot}0$, interval $115^d\ 23\frac{1}{3}^h$, accumulated rate + $7^m\ 43^s{\cdot}8$, red. decl. 2° 58′ 4″ N., red. eq. T. $5^m\ 12^s{\cdot}26$ *add*, true alt. 30° 21′ 7″, sum of logs. 9·343655, hour-angle $3^h\ 44^m\ 7^s$, M.T. ship February $28^d\ 3^h\ 49^m\ 19^s$. *Longitude* 65° 52′ 45″ E.

By *Raper:* True alt. 30° 21′ 0″, log. sine sq. 9·343684, hour-angle $3^h\ 44^m\ 8^s$. *Longitude* 65° 53′ E.

4. Interval 28^d, rate $5^s{\cdot}8$, interval $35^d\ 6^h$, accumulated rate — $3^m\ 24^s{\cdot}4$, Green. date April $15^d\ 6^h\ 12^m\ 47^s$, red. decl. 9° 50′ 41″ N., red. eq. T. *subt.* $0^m\ 1^s{\cdot}0$, true alt. 16° 17′ 9″, sum of logs. 9·578142 hour-angle $5^h\ 3^m\ 47^s$, M.T. ship April $14^d\ 18^h\ 56^m\ 12^s$. *Longitude* 169° 8′ 45″ W.

By *Raper:* True alt. 16° 16′ 56″, log. sine sq. 9·578204, hour-angle $5^h\ 3^m\ 48^s$. *Longitude* 169° 9′ 0″ W.

5. Interval 28^{d}, rate $2^{s}{\cdot}5$ *losing*, interval 108^{d}, accumulated rate + $4^{m}\ 30^{s}$, Green. date May $19^{d}\ 0^{h}\ 29^{m}\ 10^{s}$, red. decl. 19° 45′ 48″ N., red. eq. T. $3^{m}\ 45^{s}{\cdot}78$ *subt.* from A.T., true alt. 30° 41′ 2″, sum of logs. 9·340852, hour angle $3^{h}\ 43^{m}\ 20^{s}$, M.T. ship May $19^{d}\ 3^{h}\ 39^{m}\ 34^{s}$. *Longitude* 47° 36′ 0″ E.

By *Raper:* True alt. 30° 40′ 55″, log. sine sq. 9·340885, hour-angle $3^{h}\ 43^{m}\ 21^{s}$. *Longitude* 47° 36′ 15″ E.

6. Interval 22^{d}, rate $9^{s}.4$ *gaining*, interval $33^{d}\ 18^{h}$, accumulated rate — $5^{m}\ 17^{s}{\cdot}2$, Green. date June $14^{d}\ 17^{h}\ 56^{m}\ 42^{s}$, red. decl. 23° 18′ 19″ N., red. eq. T. + $0^{m}\ 4^{s}$, sum of logs. 9·277920, hour-angle $3^{h}\ 26^{m}\ 31^{s}$, M.T. ship June $14^{d}\ 20^{h}\ 33^{m}\ 33^{s}$. *Longitude* 39° 12′ 45″ E.

By *Raper:* True alt. 39° 50′ 38″, log. sine sq. 9·277969, hour-angle $3^{h}\ 26^{m}\ 32^{s}$. *Longitude* 39° 12′ 30″ E.

7. Interval 26^{d}, rate $4^{s}{\cdot}7$ *gaining*, interval 34^{d}, accumulated rate — $2^{m}\ 40^{s}$, Green. date July $5^{d}\ 0^{h}\ 33^{m}\ 8^{s}$, red. decl. 22° 48′ 19″ N., red. eq. T. + $4^{m}\ 14^{s}{\cdot}6$, true alt. 48° 47′ 5″, sum of logs. 9·166687, hour-angle $3^{h}\ 0^{m}\ 13^{s}$. *Longitude* 52° 16′ 30″ W.

By *Raper:* True alt. 48° 46′ 55″, log. sine sq. 9·166744, hour-angle $3^{h}\ 0^{m}\ 14^{s}$. *Longitude* 52° 16′ 45″ W.

8. Interval 21^{d}, rate $2^{s}{\cdot}6$ *gaining*, interval $104^{d}\ 2^{h}$, accumulated rate — $4^{m}\ 31^{s}$, Green. date August $13^{d}\ 2^{h}\ 20^{m}\ 42^{s}$, red. decl. 14° 40′ 29″ N., red. eq. T. $4^{m}\ 40^{s}{\cdot}0$ *add*, true alt. 27° 23′ 29″, sum of logs. 9·162297, hour-angle $2^{h}\ 59^{m}\ 16^{s}$, M.T. ship August $12^{d}\ 21^{h}\ 5^{m}\ 24^{s}$. *Longitude* 78° 49′ 30″ W.

By *Raper:* True alt. 27° 23′ 25″, log. sine sq. 9·162328, hour-angle $2^{h}\ 59^{m}\ 16^{s}$. *Longitude* 78° 49′ 30″ W.

9. Interval 28^{d}, rate $0^{s}{\cdot}7$ *gaining*, interval $31^{d}\ 19^{h}$, accumulated rate $22^{s}{\cdot}1$, Green. date August $21^{d}\ 19^{h}\ 12^{m}\ 18^{s}$, red. decl. 8° 23′ 9″ N., red. eq. T. $0^{m}\ 0^{s}{\cdot}09$ *subt.*, true alt. 44° 44′ 40″, sum of logs. 9·058604, hour-angle $2^{h}\ 38^{m}\ 11^{s}$, M.T. ship September $1^{d}\ 2^{h}\ 38^{m}\ 11^{s}$. *Longitude* 111° 28′ 15″ E.

By *Raper:* True alt. 44° 44′ 36″, log. sine sq. 9·058637, hour-angle $2^{h}\ 38^{m}\ 12^{s}$. *Longitude* 111° 28′ 30″ E.

10. Interval $97^{d}\ 9^{h}$, accumulated rate — $7^{m}\ 38^{s}$, Green. date October $25^{d}\ 8^{h}\ 35^{m}\ 42^{s}$, red. decl. 12° 13′ 10″ S., red. eq. T. $15^{m}\ 51^{s}{\cdot}3$ *subt.*, true alt. 40° 31′ 1″, sum of logs. 9·009541, hour-angle $2^{h}\ 29^{m}\ 10^{s}$, M.T. ship October $25^{d}\ 2^{h}\ 13^{m}\ 19^{s}$. *Longitude* 95° 35′ 45″ W.

By *Raper:* True alt. 40° 30′ 56″, log. sine sq. 9·009595, hour-angle $2^{h}\ 29^{m}\ 11^{s}$. *Longitude* 95° 35′ 30″ W.

11. Interval $18^{d}\ 7^{h}$, accumulated rate + $2^{m}\ 2^{s}{\cdot}6$, Green. date November $27^{d}\ 7^{h}\ 13^{m}\ 53^{s}$, red. decl. 21° 11′ 31″ S., red. eq. T. $12^{m}\ 9^{s}$ *subt.*, true alt. 34° 50′ 6″, sum of logs. 9·419665, hour-angle $4^{h}\ 6^{m}\ 44^{s}$, M.T. ship November $26^{d}\ 19^{h}\ 41^{m}\ 7^{s}$. *Longitude* 173° 11′ 30″ W.

By *Raper:* True alt. 34° 49′ 57″, log. sine sq. 9·419704, hour-angle $4^{h}\ 6^{m}\ 45^{s}$. *Longitude* 173° 11′ 45″ W.

12. Interval 28^{d}, rate $9^{s}{\cdot}3$ *gaining*, interval $148^{d}\ 18^{h}$, accumulated rate — $23^{m}\ 3^{s}{\cdot}3$, Green. date December $24^{d}\ 17^{h}\ 42^{m}\ 56^{s}{\cdot}7$, red. decl. 23° 24′ 51″ S., true alt. 10° 42′ 56″, sum of logs. 9·638735, hour-angle $5^{h}\ 30^{m}\ 14^{s}$, M.T. ship December $24^{d}\ 18^{h}\ 29^{m}\ 53^{s}$. *Longitude* 11° 44′ 0″ E.

By *Raper:* True alt. 10° 42′ 44″, log. sine sq. 9·638766, hour-angle $5^{h}\ 30^{m}\ 15^{s}$. *Longitude* 11° 43′ 45″ E.

13. Interval 31^{d}, rate $6^{s}{\cdot}9$ *losing*, interval $80^{d}\ 14^{h}$, accumulated rate $9^{m}\ 16^{s}$, Green. date January $1^{d}\ 14^{h}\ 0^{m}\ 38^{s}$, red. decl. 22° 57′ 43″ S., red. eq. T. + $4^{m}\ 3^{s}{\cdot}13$, true alt. 39° 9′ 31″, sum of logs. 9·362397, hour-angle $3^{h}\ 49^{m}\ 28^{s}$. *Longitude* 151° 46′ 45″ W.

By *Raper:* True alt. 39° 9′ 28″, log. sine sq. 9·362413, hour-angle $3^{h}\ 49^{m}\ 28^{s}$. *Longitude* 151° 46′ 45″ W.

14. Interval 31^{d}, rate $8^{s}{\cdot}3$ *gaining*, interval $71^{d}\ 22^{h}$, accumulated rate $9^{m}\ 56^{s}{\cdot}9$, Green. date February $10^{d}\ 21^{h}\ 33^{m}\ 26^{s}$, red. decl. 14° 3′ 28″ S., red. eq. T. $14^{m}\ 27^{s}{\cdot}3$ *add*, true alt. 12° 17′ 54″, sum of logs. 9·174240, hour-angle $3^{h}\ 1^{m}\ 53^{s}$. *Longitude* 5° 13′ 0″ W.

By *Raper:* True alt. 12° 17′ 48″, log. sine sq. 9·174311, hour-angle $3^{h}\ 1^{m}\ 54^{s}$. *Longitude* 5° 13′ 15″ W.

15. Interval 34^d, rate $2^s{\cdot}5$ *losing*, interval 52 days, accumulated rate + 2^m 10^s, Green. date October 26^d 0^h 26^m 10^s, red. decl. 12° 26′ 44″ S., red. eq. T. 15^m $55^s{\cdot}4$ *subt.*, true alt. 25° 10′ 24″, sum of logs. 9·287490, hour-angle 3^h 28^m 59^s. *Longitude* 62° 46′ 0″ W.

By *Raper:* True alt. 25° 10′ 13″, log. sine sq. 9·287556, hour-angle 3^h 29^m 0^s. *Longitude* 62° 46′ 15″ W.

16. Interval 18^d, rate $5^s{\cdot}4$ *losing*, interval 17 days (nearly), accumulated rate + 1^m 32^s, Green. date February 5^d 23^h 59^m 40^s, red. decl. 15° 37′ 4″ S., red. eq. T. + 14^m $18^s{\cdot}4$, true alt. 21° 21′ 7″, sum of logs. 9·466109, hour-angle 4^h 21^m 55^s. *Longitude* 69° 8′ 15″ E.

By *Raper:* True alt. 21° 20′ 57″, log. sine sq. 9·466144, hour-angle 4^h 21^m 56^s. *Longitude* 69° 8′ 30″ E.

17. Interval 48^d, rate $3^s{\cdot}3$, interval 72^d 19^h, accumulated rate — 4^m 0^s, Green. date April 30^d 18^h 54^m 3^s, red. decl. 15° 0′ 1″ N., red. eq. T. 2^m 58^s *subt.*, true alt. 28° 18′ 45″, sum of logs. 9·460265, hour-angle 4^h 19^m 57^s. *Longitude* 140° 44′ 0″ E.

By *Raper:* True alt. 28° 18′ 33″, sine sq. 9·460308, hour-angle 4^h 19^m $57\frac{1}{2}^s$. *Longitude* 140° 44′ 7″·5 E.

18. Interval 58^d, rate $1^s{\cdot}6$, interval 99^d 16^h, accumulated rate — 2^m $39^s{\cdot}4$, Green. date April 20^d 15^h 48^m $55^s{\cdot}8$, red. decl. 11° 43′ 45″ N., red. eq. T. *subt.* 1^m 15^s, true alt. 31° 59′ 22″, sum of logs. 9·360725, hour-angle 3^h 48^m 59^s. *Longitude* at sight 179° 42′ E., diff. *longitude* + 29′ 54″ give *longitude* at noon 179° 48′ 6″ W.

By *Raper:* True alt. 31° 59′ 18″, sine sq. 9·360741, hour-angle 3^h 48^m 59^s. *Longitude* at noon 179° 48′ 6″ W.

19. Interval 48^d, rate $1^s{\cdot}25$, interval 113^d 8^h, accumulated rate + 2^m $21^s{\cdot}7$, Green. date August 21^d 8^h 22^m 2^s, red. decl. 12° 2′ 3″ N., red. eq. T. + 2^m 56^s, true alt. 34° 2′ 1″, sum of logs. 9·330155, hour-angle 3^h 40^m 22^s. *Longitude* at sights 179° 52′ 0″ W. + 29′ 54″ W. *Longitude* at noon 179° 38′ 6″ E.

By *Raper:* True alt. 34° 1′ 51″, log. sine sq. 9·330197, hour-angle 3^h 40^m 23^s. *Longitude* 179° 37′ 51″ E.

20. Interval 27^d, rate $0^s{\cdot}3$ *gaining*, interval 20^d, accumulated rate — 6^s, Green. date March 20^d 1^h 32^m 46^s, red. decl. 0° 8′ 39″ S., red. eq. T. + 7^m 37^s, true alt. 29° 1′ 4″, sum of logs. 9·410708, hour-angle 4^h 3^m 56^s, M.T. ship March 19^d 20^h 3^m 41^s. *Longitude* 82° 16′ 15″ W.

By *Raper:* True alt. 29° 0′ 57″, log. sine sq. 9·410733, hour-angle 4^h 3^m 56^s. *Longitude* 82° 16′ 15″ W.

21. Interval 32^d, rate $0^s{\cdot}8$ *gaining*, interval 113^d 21^h, accumulated rate — 1^m 31^s, Green. date September 22^d 20^h 54^m 32^s, red. decl. 0°, red. eq. T. — 7^m 33^s, hour-angle 2^h 57^m 55^s, M.T. ship September 22^d 20^h 54^m 32^s. *Longitude* 0° 0′ 0″.

By *Raper:* True alt. 45° 31′ 5″, hour-angle 2° 57′ 56″. *Longitude* 0° 0′ 15″ W.

SUMNER'S METHOD, *Page* 248.

1. 1st red. decl. 7° 47′ 51″ S.; 1st red. eq. T. 12^m $39^s{\cdot}95$ (*added* to A.T.); 1st true alt. 29° 57′ 17″; lat. 49° 10′ gives hour-angle 1^h 26^m 45^s; long. 178° 45′ 15″ E. (A). Lat. 49° 40′ gives hour-angle 1^h 19^m 50^s; long. 180° 29′ 0″ E., or 179° 31′ 0″ W. (A′). 2nd red. decl. 7° 43′ 6″ S.; 2nd red. eq. T. 12^m $37^s{\cdot}5$ (*added* to A.T.); 2nd true alt. 15° 55′ 57″: lat. 49° 10′ gives hour-angle 3^h 38^m 4^s; long. 179° 58′ 7″·5 E. Lat. 49° 40′ N. gives hour-angle 3^h 36^m 3^s; long. 179° 27′ 52″·5 E. The line of bearing when the first altitude was taken trends N.E. by E. ¾ E. Azimuth S. 25° E. Line of bearing B B′ N.N.W. ¾ W westerly, azimuth S. 57½° W. The position of ship when the second altitude was observed was lat. 49° 20′ N., long. 178° 48′ E.

2. 1st red. decl. 19° 44′ 29″ N.; 1st red. eq. T. — 3^m 46^s; true alt. 49° 8′ 2″; lat. 48° 30′ gives hour-angle 2^h 24^m 49^s; M.T. ship May 18^d 21^h 31^m 25^s; long. 7° 33½′ W. (A). Lat. 49° 0′ gives hour-angle 2^h 22^m 54^s; M.T. ship May 18^d 21^h 33^m 20^s; long. 7° 4¾′ W.; 2nd red. decl. 19° 47′ 31″ N.; red. eq. T. 3^m $45^s{\cdot}4$ *subt.*; true alt. 40° 56′ 2″; lat. 48° 30′ gives hour-angle 3^h 19^m 36^s; long. 6° 21¾′ W. (B). Lat. 49° 0′ gives hour-angle 3^h 18^m 37^s; long. 6° 36½′ W. The line of bearing when the first altitude was taken N.N.E. ¾ E., true. Azimuth S. 59° E. Line of bearing B B′ N. by W. ½ W. westerly, azimuth S. 71¾ W. The position of ship when the second altitude was observed was lat. 49° 1′ N., long. 6° 37½′ W.

3. 1st red. decl. 16° 33′ 21″ S.; 1st red. eq. T. $16^m\ 9^s{\cdot}1$ *subt.*; 1st true alt. 19° 58′ 31″; lat. 48° 10′ N. gives hour-angle $1^h\ 59^m\ 49^s$; long. 11° 15′ W. (A). Lat. 48° 40′ N. gives hour-angle $1^h\ 54^m\ 35^s$; long. 9° 56½′ W. (A′). 2nd red. decl. 16° 37′ 14″ S.; 2nd red. eq. T. $16^m\ 8^s$ *subt.*; 2nd true alt. 10° 57′ 46″; lat. 48° 10′ gives hour-angle $3^h\ 23^m\ 30^s$; long. 10° 23¾′ W. (B). Lat. 48° 40′ N. gives hour-angle $3^h\ 20^m\ 52^s$; long. 11° 3¼′ W. (B′). The line of bearing at first observation trends N.E. by E. ¼ E. and S.W. by W. ¼ W. Azimuth S. 31° E. 2nd line of bearing B B′ N.W. ¼ N., azimuth S. 48° W. The ship's position at time of second observation is lat. 48° 23′ N., long. 10° 41′ W.

4. 1st red. decl. 16° 32′ 34″ S.; 1st red. eq. T. $14^m\ 3^s{\cdot}0$ *add*; 1st true alt. 19° 59′ 26″; lat. 48° 10′ gives hour-angle $1^h\ 59^m\ 46^s{\cdot}5$; long. 0° 44′ 52½″ W. (A). Lat. 48° 40′ gives hour-angle $1^h\ 54^m\ 33^s$; long. 0° 33½′ E. (A′). 2nd true alt. 11° 0′ 52″; 2nd decl. 16° 28′ 38″ S.; 2nd red. eq. time $14^m\ 4^s$ *add*; lat. 48° 10′ gives hour-angle $3^h\ 24^m\ 3^s$; long. 0° 14′ E. (B). Lat. 48° 40′ gives hour-angle $3^h\ 21^m\ 26^s$; long. 0° 25¼′ W. (B′). The line of bearing at first observation runs N.E. by E. ¼ E. and S.W. by W. ¼ W. Azimuth S. 31° E. 2nd line of bearing B B′ N.W. ¼ N. northerly, azimuth S. 49° W. The ship's position at second observation is lat. 48° 18′ N., long 0° 4′ E.

5. 1st red. decl. 4° 28′ 40″ N.; 1st eq. T. $4^m\ 1^s$ *add*; 1st true alt. 27° 57′ 14″; lat. 54° 0′ gives hour-angle $3^h\ 17^m\ 42^s$; long. 0° 19¾′ E. (A). Lat. 51° 30′ gives hour-angle $3^h\ 15^m\ 45^s$; long. 0° 49′ E. (A′). 2nd red. decl. 4° 33′ 43″ N.; 2nd red. eq. T. $3^m\ 57^s{\cdot}23$ *add*; 2nd true alt. 37° 46′ 48″; lat. 51° 0′ gives hour-angle $1^h\ 54^m\ 22^s$; long. 0° 5¼′ W. (B). Lat. 51° 30′ gives hour-angle $1^h\ 50^m\ 2^s$; long. 1° 10¼′ W. (B′). The line of bearing at first observation trends N.N.E. ¾ E. and S.S.W. ¾ W. Azimuth S. 59° E. 2nd observation B B′ N.W ¾ W., azimuth S. 36½′ W. The position of ship at second observation is lat. 51° 2′ N., long. 0° 9½′ W.

6. 1st red. decl. 2° 21′ 53″ N.; 1st red. eq. T. $5^m\ 40^s{\cdot}59$ *add*; 1st true alt. 36° 48′ 55″; lat. 51° 40′ gives hour-angle $1^h\ 35^m\ 19^s$; long. 180° 59′ 30″ E., or 179° 0½′ W. (A). Lat. 51° 10′ gives hour-angle $1^h\ 40^m\ 38^s$; long. 179° 39¾′ E. (A′); 2nd red. decl. 2° 27′ 56″ N.; 2nd red. eq. T. $5^m\ 35^s{\cdot}8$ *add*; 2nd true alt. 15° 23′ 35″; lat. 51° 40′ N.; hour-angle $4^h\ 32^m\ 10^s$; long. 180° 9′ E., or 179° 51′ W. (B). Lat. 51° 10′ gives hour-angle $4^h\ 33^m\ 5^s$; long. 180° 22¾′ E., or 179° 37¼′ W. The line of bearing at first observation trends S.W. by W. ¼ W. and N.E. by E. ¼ E. Azimuth S. 31° E. 2nd line of bearing B B′ S. by E. ¼ E. easterly, azimuth S. 74½° W. The position of the ship at the second observation is lat. 51° 0′ N., long. 179° 32½′ W.

7. 1st red. decl. 23° 4′ 6″ N; 1st red. eq. T. $0^m\ 46^s{\cdot}1$ *subt.*, 1st true alt. 31° 19′ 58″; lat. 48° 0′; hour-angle $4^h\ 32^m\ 43^s$; long. 38° 5¼′ E. (A). Lat. 48° 20′ gives hour-angle $4^h\ 32^m\ 44^s$; long. 38° 5′ E. (A′). 2nd red. decl. 23° 4′ 30″ N.; 2nd red. eq. T. $0^m\ 45^s$ *subt.*, 2nd alt. 53° 1′ 42″; lat. 48° 0′ gives hour-angle $2^h\ 17^m\ 47^s$; long. 37° 43′ E. (B). Lat. 48° 20′ gives hour-angle $2^h\ 16^m\ 36^s$; long. 38° 0¼′ E. (B′). The line of bearing at first observation trends N. and S. Azimuth E. 2nd line of bearing B B′ N.N.E. ¾ E., azimuth S 59° E. The position of the ship at the second observation is lat. 48° 15′ N., long. 37° 56½′ E.

8. 1st red. decl. 19° 6′ 55″ S.; 1st red. eq. T. $12^m\ 24^s{\cdot}8$ *add*; 1st true alt. 9° 46′ 38″, lat. 51° 15′ N. gives hour-angle $2^h\ 56^m\ 8^s$; long. 179° 36¾′ W. (A). Lat. 50° 45′ gives hour-angle $2^h\ 59^m\ 38^s$; long. 179° 30¼′ E. (A′). 2nd red. decl. 19° 4′ 30″ S.; 2nd red. eq. T. $12^m\ 27^s{\cdot}2$ *add*; 2nd true alt. 18° 40′ 21″. Lat. 51° 15′ N. gives hour-angle $0^h\ 54^m\ 18^s$; long. 178° 3¾′ E. (B). Lat. 50° 45′ gives hour-angle $1^h\ 6^m\ 9^s$; long. 178° 58½′ W (B′). The line of bearing at the first observation trends S.W. ¼ W. Azimuth S. 42° E. 2nd line of bearing E. by S. ¼ S., azimuth S. 14° W. The position of the ship at the second observation is lat. 50° 50′ N., long. 179° 27′ W.

9. 1st red. decl. 0° 10′ 13″ N.; 1st red. eq. T. $7^m\ 22^s{\cdot}3$ *add*; 1st true alt. 22° 59′ 25″, lat. 50° 10′ N. gives hour-angle $3^h\ 30^m\ 45^s$; long. 0° 35′ 15″ W. (A). Lat. 50° 50′ gives hour-angle $3^h\ 28^m\ 16^s$; long. 0° 2′ E. (A′). 2nd red. decl. 0° 15′ 48″ N; 2nd eq. T. $7^m\ 18^s$ *add*; 2nd true alt. 32° 40′ 10″. Lat. 50° 10′ N. gives hour-angle $2^h\ 12^m\ 37^s$; long. 0° 16¼′ E. (B). Lat. 50° 50′ gives hour-angle $2^h\ 7^m\ 34^s$; long. 0° 59½′ W. (B′) The line of bearing at first observation trends N.N.E. ¾ E. and S.S.W. ¾ W. Azimuth S. 59° E. 2nd line of bearing B B′ N.W. ½ W., azimuth S. 39½° W. The position of the ship at the second observation is lat. 50° 47½′ N., 0° 54′ W.

10. 1st red. decl. 23° 11′ 2″ S.; 1st red. eq. T. $2^m\ 39^s{\cdot}3$ *add*; 1st true alt. 9° 42′ 18″; lat. 50° 0′ gives hour-angle $2^h\ 29^m\ 7^s$; long. 0° 39¼′ W. (A). Lat. 50° 20′ gives hour-angle $2^h\ 26^m\ 2^s$; long. 0° 7¼′ E. (A′). 2nd red. decl. 23° 10′ 30″ S.; 2nd red. eq. T. $2^m\ 43^s{\cdot}2$ *add*; 2nd true alt. 15° 51′ 26″; lat. 50° 0′ gives hour-angle $0^h\ 53^m\ 48^s$; long. 1° 9¼′ E. (B). Lat. 50° 20′ gives hour-angle $0^h\ 43^m\ 42^s$; long. 1° 22¼′ W. (B′). The line of bearing at the first observation trends N.E. by E. and S.W. by W. Azimuth S. 34° E. 2nd line of bearing B B′ W. by N., azimuth S. 11½° W. The position of the ship at the second observation is lat 50° 9′ N., long. 0.

11. 1st red. decl. 23° 22′ 55″ N.; 1st red. eq. T. + $0^m\ 30^s$; 1st true alt. 52° 1′ 31″; lat. 48° 50′ gives hour-angle $2^h\ 23^m\ 32^s$; long. 48° 13¾′ E. (A). Lat. 48° 10′ gives hour-angle $2^h\ 25^m\ 42^s$; long. 47° 41¼′ E. (A′). 2nd red. decl. 23° 23′ 8″ N.; 2nd red. eq. T. + $0^m\ 31^s{\cdot}3$; 2nd true alt. 63° 45′ 7″. Lat. 48° 50′ gives hour-angle $0^h\ 32^m\ 34^s$; long. 47° 23¾′ E. (B). Lat. 48° 10′ gives hour-angle $0^h\ 43^m\ 34^s$; long. 50° 8¾′ E. (B′). The line of bearing at the first observation trends S.S.W. ½ W. and N.N.E. ½ E. Azimuth S. 62° E. 2nd line of bearing E.S.E., azimuth S. 22° W. The position of the ship at the second observation is lat. 48° 29′ N., long. 48° 49½′ E.

12. 1st red. decl. 13° 30′ 29″ S.; 1st red. eq. T. *subt.* $16^m\ 11^s$; 1st true alt. 28° 28′ 14″; lat. 47° 30′ gives hour-angle $0^h\ 35^m\ 45^s{\cdot}5$; long. 75° 17′ 7″·5 W. (A). Assumed lat. 47° 50′ this gives hour-angle $0^h\ 21^m\ 33^s$; long. 71° 44′ W. (A′). Red. decl. 13° 33′ 23″ S., red. eq. T. $16^m\ 11^s{\cdot}5$ *subt.*; lat. 47° 30′ gives hour-angle $3^h\ 1^m\ 8^s$; long. 73° 33′ 52½″ W. (B). Lat. 47° 50′ gives hour-angle $2^h\ 59^m\ 13^s{\cdot}5$; long. 74° 2½′ W. (B′). The line of bearing at the first observation trends E. ¾ N. and W. ¾ S. Azimuth S. 8½° E. 2nd line of bearing B B′ N. 45° W., azimuth S. 45° W. The position of the ship at the second observation is lat. 47° 39′ N., long. 73° 46′ W.

TRUE AZIMUTHS, *Page* 254.

1. S. 98° 43′ 30″ E.
2. S. 41 58 18 E.
3. N. 75 58 4 W.
4. S. 60 9 36 W.
5. N. 123° 56′ W.
   or S. 56 4 W.
6. East.

AZIMUTHS, *Page* 265.

NOTE.—In each of the following examples the second line gives the answers by RAPER's Tables, and the third line is the answers by Time Azimuth Tables.

No.	Green. date.	Red. decl.	True alt.	Sum of logs.	True azimuth.	Error.	Deviation.
1.	Jan. $23^d\ 23^h\ 46^m\ 7^s$	19° 12′ 38″ S	38° 34′ 32″	19·731652	N 94° 28′ 58″ E	15° 43′ 58″ E	11° 7′ 58″ E
			38 34 20	9·731664	N 94 29 3 E	15 44 3 E	11 8 3 E
	Lat. 26° S. and decl. 19° S., app. time at ship $8^h\ 18^m$ A.M.				N 94 32 0 E	15 47 0 E	11 11 0 E
2.	Feb. 28 9 43 4	7 48 55 S	27 7 43	19·292905	S 52 35 50 W	10 5 50 E	1 24 10 W
			27 7 33	9·292965	S 52 36 4 W	10 6 4 E	1 23 56 W
	Lat. 39° N. and decl. 8° S., app. time at ship $3^h\ 4^m$ P.M.				S 52 47 0 W	10 17 0 E	1 13 0 W
3.	Mar. 27 0 34 12	2 35 43 N	29 41 3	19·702752	N 89 29 56 W	10 44 55 W	7 14 56 W
			29 40 58	9·702753	N 89 29 55 W	10 44 55 W	7 14 55 W
	Lat. 4° N. and decl. 3° N., app. time at ship $4^h\ 0^m$ P.M.				N 89 36 0 W	10 51 0 W	7 21 0 W
4.	April 2 19 0 8	5 13 8 N	11 50 41	19·650673	S 83 57 30 W	6 2 30 W	15 12 30 W
			11 50 28	9·650706	S 83 57 45 W	6 2 15 W	15 12 15 W
	Lat. 50° N. and decl. 5° N., app. time at ship $5^h\ 12^m$ P.M.				S 83 59 0 W	6 1 0 W	15 11 0 W
5.	May 26 21 9 32	21 16 19 N	43 19 41	19·416948	S 61 28 9 E	0 16 51 E	16 1 51 E
			43 19 34	9·417010	S 61 28 27 E	0 16 33 E	16 1 33 E
	Lat. 55° N. and decl. 21° N., app. time at ship $9^h\ 8^m$ A.M.				S 60 56 0 E	0 49 0 E	16 34 0 E
6.	June 14 11 4 40	23 17 34 N	11 8 48	19·121249	N 42 38 34 E	5 10 11 W	16 20 11 W
			11 8 43	9·121301	N 42 38 44 E	5 10 1 W	16 20 1 W
	Lat. 43° S. and decl. 23° N., app. time at ship $8^h\ 56^m$ A.M.				N 42 32 0 E	5 17 0 W	16 27 0 W
7.	July 31 1 6 46	18 17 18 N	43 35 48	19·602138	S 78 28 18 E	3 8 18 W	5 41 42 E
			43 35 40	9·602159	S 78 28 25 E	3 8 25 W	5 41 35 E
	Lat. 38° N. and decl. 18° N., app. time at ship $8^h\ 48^m$ A.M.				S 78 10 0 E	2 50 0 W	6 0 0 E
8.	Aug. 23 2 57 38	11 26 10 N	7 43 28	19·759892	N 81 20 19 E	15 0 19 E	10 29 41 W
			7 43 15	9·759924	N 81 20 1 E	15 0 1 E	10 29 59 W
	Lat. 51° N. and decl. 11° N., app. time at ship $5^h\ 52^m$ A.M.				N 81 29 0 E	15 9 0 E	10 21 0 W
9.	Aug. 31 10 29 17	8 31 3 N	40 0 4	19·257101	S 50 19 16 E	19 59 29 E	25 29 29 E
			39 59 55	9·257175	S 50 19 33 E	19 59 12 E	25 29 12 E
	Lat. 48° N. and decl. 9° N., app. time at ship $9^h\ 36^m$ A.M.				S 49 53 0 E	20 26 0 E	25 56 0 E

No.	Green. date.	Red. decl.	True alt.	Sum of logs.	True azimuth.	Error.	Deviation.
10.	Nov. 25 7 30 28	20 49 9 S	34 2 21	19·696131	N 89 37 36 W	2 26 21 W	11 48 21 W
			34 2 15	9·696141	N 89 37 41 W	2 26 26 W	11 48 26 W
	Lat. 40° S. and decl. 21° S., app. time at ship 4^h 8^m P.M.				N 89 30 0 W	2 19 0 W	11 41 0 W
11.	Dec. 24 6 24 40	23 25 30 S	12 43 17	19·219316	S 48 2 26 W	5 23 49 W	19 6 11 E
			12 43 3	9·219394	S 48 2 42 W	5 23 33 W	19 6 27 E
	Lat. 36° N. and decl. 23° S., app. time at ship 3^h 28^m P.M.				S 48 10 0 W	5 16 0 W	19 14 0 E
12.	June 13 23 18 18	23 16 6 N	36 0 0	19·555202	N 106 22 8 E	19 10 53 E	36 10 53 E
			35 59 48	9·555271	N 106 21 44 E	19 10 29 E	36 10 29 E
	Lat. 60° N. decl. 23° N., app. time at ship 8^h 8^m A.M.				N 106 13 0 E	19 2 0 E	36 2 0 E

13. Red. eq. T. 6^m 7^s *subt.* from M.T.; app. time at ship Jan. 6^d 4^h 57^m 27^s P.M.; red. decl. 22° 29′ 18″ S.; true alt. 26° 46′ 54″; sum of logs. 19·732974; true azimuth N. 94° 40′ 18″ W.; error of compass 10° 0′ 18″ W.; deviation 17° 50′ 18″ W.

By *Raper*:—True alt. 26° 46′ 47″; sine sq. 9·732991; true azimuth N. 94° 40′ 27″ W.; error of compass 10° 0′ 27″ W.; deviation 17° 50′ 27′ W.

By *Time Azimuth Tables*:—Lat. 48° S., decl. 22½° S. (*same* name), and app. time at ship 4^h 56^m P.M. gives true azimuth S. 85° 42′ W.; error of compass 9° 38′ W.; deviation 17° 28′ W.

14. Red. eq. T. 0^m $13^s·2$ *subt.* from M.T.; app. time at ship April 14^d 8^h 56^m 13^s A.M.; red. decl. 9° 30′ 18″ N.; true alt. 35° 43′ 10″; sum of logs. 19·398074; true azimuth S. 60° 0′ 37″ E.; error of compass 15° 55′ 38″ E.; deviation 3° 44′ 22″ W.

By *Raper*:—True alt. 35° 43′ 3″; sine sq. 9·398124; true azimuth S. 60° 0′ 50″ E.; error of compass 15° 55′ 25″ E.; deviation 3° 44′ 35″ W.

By *Time Azimuth Tables*:—Lat. 48° N., decl. 9⅝° N., and app. time at ship 8^h 56^m A.M. gives true azimuth N. 119° 20′ E.; error of compass 15° 16′ E.; deviation 4° 24′ W.

15. Red. eq. T. 13^m $24^s·7$ *subt.* from M.T.; app. time at ship Jan. 29^d 3^h 23^m 10^s P.M.; red. decl. 17° 51′ 15″ S.; true alt. 13° 47′ 28″; sum of logs. 19·240391; true azimuth S. 49° 17′ 52″ W.; error of compass 31° 32′ 8″ W.; deviation 11° 2′ 8″ W.

By *Raper*:—True alt. 13° 47′ 13″; sine sq. 9·240481; true azimuth S. 49° 18′ 12″ W.; error of compass 31° 31′ 48″ W.; deviation 11° 1′ 48″ W.

By *Time Azimuth Tables*:—Lat. 42° N., decl. 18° S. (*contrary* names), and app. time at ship 3^h 24^m P.M. gives true azimuth S. 49° 33′ W.; error of compass 31° 17′ W.; deviation 10° 47′ W.

16. Red. eq. T. 14^m 27^s *subt.* from M.T.; app. time at ship Feb. 11^d 8^h 58^m 6^s A.M.; red. decl. 14° 3′ 28″ S.; true alt. 12° 18′ 43″; sum of logs. 19·166167; true azimuth S. 45° 1′ 36″ E.; error of compass 8° 27′ 51″ W.; deviation 10° 47′ 9″ E.

By *Raper*:—True alt. 12° 18′ 37″; sine sq. 9·166231; true azimuth S. 45° 1′ 48″ E.; error of compass 8° 28′ 3″ W.; deviation 10° 46′ 57″ E.

By *Time Azimuth Tables*:—Lat. 53° N., decl. 14° S., and app. time at ship 8^h 56^m A.M. gives true azimuth S. 45° 35′ E.; error of compass 9° 1′ W.; deviation 10° 14′ E.

17. Red. eq. T. 13^m 50^s *subt.* from M.T.; app. time at ship Feb. 1^d 3^h 31^m 1^s P.M.; red. decl. 17° 4′ 22″ S.; true alt. 40° 7′ 21″; sum of logs. 19·651796; true azimuth N. 84° 5′ 32″ W.; error of compass 13° 15′ 32″ W.; deviation 16° 24′ 28″ E.

By *Raper*:—True alt. 40° 7′ 13″; sine sq. 9·651811; true azimuth N. 84° 5′ 38″ W.; error of compass 13° 15′ 38″ W.; deviation 16° 24′ 22″ E.

By *Time Azimuth Tables*:—Lat. 34° S., decl. 17° S., and app. time at ship 3^h 32^m P.M. gives true azimuth N. 84° 4′ W.; error of compass 13° 14′ W.; deviation 16° 26′ E.

18. Red. eq. T. 14^m 0^s *subt.* from M.T.; app. time at ship Feb. 20^d 9^h 11^m 19^s A.M.; red. decl. 11° 7′ 31″ S.; true alt. 11° 28′ 34″; sum of logs. 19·104778; true azimuth S. 41° 48′ 14″ E.; error of compass 44° 36′ 59″ W.; deviation 14° 36′ 59″ W.

By *Raper*:—True alt. 11° 28′ 27″; sine sq. 9·104870; true azimuth S. 41° 48′ 31″ E.; error of compass 44° 37′ 16″ W.; deviation 14° 37′ 16″ W.

By *Time Azimuth Tables*:—Lat. 60° N., decl. 11° S., and app. time at ship 9^h 12^m A.M. gives true azimuth S. 42° 6′ E.; error of compass 44° 55′ W.; deviation 14° 55′ W.

REDUCTION TO MERIDIAN, *Page* 273-274.

METHOD I.

1. Red. eq. T. 5^m $11^s·9$ *subt.* from M.T.; time from noon 14^m 2^s; red. decl. 22° 43′ 16″ S.; true alt. 30° 26′ 11″; nat. no. 1386; nat. cos. mer. zen. dist. 507967. *Latitude* 36° 45′ 1″ N.

2. Red. eq. T. 12^m $44^s·4$ *subt.* from M.T.; time from noon 15^m 16^s, red. decl. 7° 56′ 52″ S.; true alt. 38° 6′ 33″; nat. no. 1586; nat. cos. 618947. *Latitude* 43° 49′ 39″ N.

3. Red. eq. T. 7^m $43^s·2$ *subt.* from M.T.; time from noon 22^m 10^s; red. decl. 0° 17′ 21″ S.; true alt. 47° 57′ 15″; nat. no. 3506; nat. cos. 746116. *Latitude* 42° 2′ 3″ S.

4. Red. eq. T. 1^m $18^s·8$ *add* to M.T.; time from noon 18^m 33^s; red. decl. 11° 50′ 4″ N.; true alt. 61° 39′ 1″; nat. no. 2459; nat. cos. 882524. *Latitude* 39° 53′ 10″ N.

5. Red. eq. T. $2^{m}\ 50^{s}\cdot6$ *add* to M.T.; time from noon $10^{m}\ 28^{s}$; red. decl. 21° 39′ 51″ N.; true alt. 30° 33′ 8″; nat. no. 771; nat. cos. 509094. *Latitude* 37° 43′ 56″ S.

6. Red. eq. T. $0^{m}\ 59^{s}\cdot2$ *subt.* from M.T.; time from noon $15^{m}\ 5^{s}$; red. decl. 23° 26′ 3″ N.; true alt. 68° 48′ 28″; nat. no. 1419; nat cos. 933793. *Latitude* 44° 24′ 2″ N.

7. Red. eq. T. $5^{m}\ 44^{s}\cdot9$ *subt.* from M.T.; time from noon $5^{m}\ 40^{s}$; red. decl. 21° 23′ 27″ N.; true alt. 67° 52′ 44″; nat. no. 285; nat. cos. 926676. *Latitude* 0° 41′ 11″ S.

No.	Green. Date.	Time noon.	Red. decl.	True Alt.	Nat. No.	Latitude.
8.	Aug. $29^{d}\ 15^{h}\ 2^{m}\ 44^{s}$	$20^{m}\ 24^{s}$	9° 10′ 4″ N.	57° 34′ 6″	2937	41° 17′ 3″ N.
9.	Sept. 8 12 9 2	3 2	5 32 2 N.	85 30 34	86	9 57 39 N.
10.	Oct. 10 18 47 58	28 10	6 55 20 S.	36 44 4	5215	45 58 10 N.
11.	Nov. 2 17 1 29	20 5	14 58 9 S.	72 2 22	3134	32 20 17 S.
12.	Dec. 23 1 38 58	9 14	23 26 38 S.	65 23 36	504	47 58 52 S.
13.	Jan. 5 8 58 28	17 32	22 34 36 S.	58 17 34	2669	8 50 19 N.
14.	April 28 2 3 11	13 37	14 9 52 N.	56 40 4	1621	18 59 54 S.
15.	March 20 11 47 28	16 56	0 1 36 N.	70 30 47	2580	19 0 44 S.
16.	April 12 10 46 29	10 19	8 49 56 N.	80 36 18	999	0 12 19 S.
17.	Dec. 10 16 53 16	19 19	22 59 9 S.	50 13 41	1502	62 37 23 S.
18.	July 22 20 55 50	42 34	20 7 49 N.	41 8 51	5940	68 31 45 N.
19.	Mar. 11 2 15 13	18 29	3 40 48 S.	32 35 9	1574	60 59 13 S.
20.	Sept. 22 7 4 42	22 6	0 13 35 N.	43 55 22	3242	45 35 33 S.

METHOD II.

No.	Reduction.	True Alt. (Norie).	True Alt. (Raper).	Latitude (Norie).	Latitude (Raper).
1.	+ 5′ 32″	30° 26′ 11″	30° 26′ 4″	36° 45′ 1″ N.	36° 45′ 9″ N.
2.	+ 6 57	38 6 33	38 6 27	43 49 38 N.	43 49 44 N.
3.	+ 18 20	47 57 15	47 57 15	42 1 45 S.	42 1 46 S.
4.	+ 17 58	61 39 1	61 38 54	39 53 5 N.	39 53 12 N.
5.	+ 3 6	30 33 8	30 33 5	37 43 55 S.	37 43 58 S.
6.	+ 13 38	68 48 28	68 48 21	44 23 57 N.	44 24 4 N.
7.	+ 2 37	67 52 44	67 52 35	0 41 12 S.	0 41 21 S.
8.	+ 19 2	57 34 6	57 34 1	41 16 56 N.	41 17 1 N.
9.	+ 4 28	85 30 34	85 30 31	9 57 0 N.	9 57 3 N.
10.	+ 22 31	36 44 4	36 43 52	45 58 5 N.	45 58 17 N.
11.	+ 36 14	72 2 22	72 2 15	32 19 33 S.	32 19 40 N.
12.	+ 4 16	65 23 36	65 23 35	47 58 45 S.	47 58 47 S.
13.	+ 17 36	58 17 34	58 17 32	8 50 14 N.	8 50 16 N.
14.	+ 10 15	56 40 4	56 40 1	18 59 49 S.	18 59 52 S.
15.	+ 27 12	70 30 47	70 30 37	19 0 25 S.	19 0 35 S.
16.	+ 22 25	80 36 18	80 36 16	0 11 21 S.	0 11 23 S.
17.	+ 8 5	50 13 41	50 13 34	62 37 23 S.	62 37 30 S.
18.	+ 27 21	41 8 51	41 8 41	68 31 37 N.	68 31 46 N.
19.	+ 6 26	32 35 9	32 35 4	60 59 13 S.	60 59 18 S.
20.	+ 15 30	43 55 22	43 55 14	45 35 33 S.	45 35 41 S.

BY TOWSON.

No.	Aug. I.	Aug. Decl.	Index.	Aug. II.	Latitude.
1.	+ 2′ 20″	22° 45′ 36″ S.	21	+ 3′ 7″	36° 45′ 6″ N.
2.	+ 1 2	7 57 54 S.	28	+ 5 48	43 49 45 N.
3.	+ 0 4	0 17 25 S.	58	+ 18 15	42 1 55 S.
4.	+ 2 19	11 52 23 N.	41	+ 20 6	39 53 16 N.
5.	+ 1 14	21 41 5 N.	12	+ 1 52	37 43 55 S.
6.	+ 2 44	23 28 47 N.	24	+ 16 27	44 23 52 N.
7.	+ 0 21	21 23 49 N.	3½	+ 2 17	0 41 10 S.
8.	+ 2 6	9 12 10 N.	50	+ 20 52	41 17 12 N.
9.	This hour-angle exceeds the limits of the Table.				
10.	+ 3 10	6 58 30 S.	76	+ 19 25	45 58 1 N.
11.	+ 3 19	15 1 28 S.	47	+ 38 56	32 20 10 S.
12.	+ 1 1	23 27 39 S.	9	+ 5 15	47 58 48 S.
13.	+ 3 35	22 38 11 S.	33	+ 14 10	8 50 8 N.
14.	+ 1 27	14 11 19 N.	22	+ 8 48	18 59 49 S.
15.	+ 0 0	0 1 36 N.	36	+ 27 11	19 0 26 S.
16.	This hour-angle exceeds the limits of the Table.				
17.	+ 4 22	23 3 31 S.	39	+ 12 24	62 37 26 S.
18.	+ 19 22	20 27 11 N.	104	+ 46 43	68 31 37 N.
19.	+ 6 42	3 41 30 S.	42	+ 7 6	60 59 15 S.
20.	+ 0 4	0 13 39 N.	57	+ 15 21	45 35 38 S.

MERIDIAN ALTITUDE OF STAR, *Page* 276.

		NORIE.		RAPER.	
No.	Declination.	True Alt.	Latitude.	True Alt.	Latitude.
1.	28°28′23″N.	75° 5′ 55″S.	43°22′ 28″N.	75° 5′ 46″S.	43°22′ 37″N.
2.	45 52 50 N.	53 53 45 N.	9 46 35 N.	53 53 38 N.	9 46 28 N.
3.	38 41 6 N.	49 55 2 N.	1 23 52 S.	49 55 1 N.	1 23 53 S.
4.	49 27 44 N.	51 46 49 N.	11 14 33 N.	51 46 39 N.	11 14 23 N.
5.	10 34 23 S.	63 13 18 S.	16 12 19 N.	63 13 17 S.	16 12 20 N.
6.	57 48 25 S.	40 5 30 S.	7 53 55 S.	40 5 20 S.	7 53 45 S.
7.	14 33 38 N.	78 11 26 S.	26 22 12 N.	78 11 18 S.	26 22 20 N.
8.	22 55 55 N.	68 15 54 N.	1 11 49 N.	68 15 49 N.	1 11 44 N.
9.	16 16 44 N.	29 52 9 N.	43 51 7 S.	29 51 59 N.	43 51 17 S.
10.	62 28 42 S.	75 4 59 S.	47 33 41 S.	75 4 54 S.	47 33 36 S.
11.	8 10 23 S.	30 16 28 S.	51 33 9 N.	30 16 20 S.	51 33 17 N.
12.	44 52 45 N.	20 7 12 N.	25 0 3 S.	20 7 2 N.	25 0 13 S.
13.	8 34 34 N.	60 45 36 N.	20 39 50 S.	60 45 27 N.	20 39 59 S.
14.	16 34 4 S.	58 55 9 N.	47 38 55 S.	58 55 5 N.	47 38 59 S.
15.	19 46 10 N.	79 42 38 S.	30 3 32 N.	79 42 30 S.	30 3 40 N.
16.	26 10 49 S.	68 42 51 S.	4 53 40 S.	68 42 48 S.	4 53 37 S.
17.	60 22 1 S.	9 52 32 S.	19 45 27 N.	9 52 24 S.	19 45 35 N.
18.	30 13 5 S.	70 3 15 N.	50 9 50 S.	70 3 14 N.	50 9 51 S.

SOUNDINGS, *Page* 312.

1. The nearest high water to time of sounding is June $16^d\ 6^h\ 4^m$ A.M. Time from high water $0^h\ 42^m$; height above half tide 9 ft. 9 in.; $0^h\ 42^m$ and 9 ft. 9 in. give correction + 9 ft. 1 in.; half spring range 9 ft. 6 in. + correction 9 ft. 1 in. = Correction for soundings *subt.* 18 ft. 7 in.

2. Time from high water $1^h\ 7^m$; height above half tide 5 ft. 1 in.; $1^h\ 7^m$ and 5 ft. 1 in. give correction + 4 ft. 3 in.; half spring range 6 ft. 9 in. + correction 4 ft. 3 in. = Correction for soundings *subt.* 11 ft. 0 in.

3. Time from high water $2^h\ 4^m$; height above half tide 4 ft. 11 in.; $2^h\ 4^m$ and 4 ft. 11 in. give correction + 2 ft. 4 in.; half spring range 5 ft. 9 in. + corr. 2 ft. 4 in. = Correction for soundings *subt.* 8 ft. 1 in.

4. Nearest high water to time of sounding is October $23^d\ 11^h\ 18^m$ P.M. Time from high water $3^h\ 56^m$; half spring range 7 ft. 2 in.; height above half tide 7 ft. 4in.; $3^h\ 56^m$ and 7 ft. 4 in = correction — 3 ft. 5 in. Correction for soundings *subt.* 3 ft. 9 in.

5. Standard port of reference, Liverpool; constant for time — $0^h\ 55^m$; constant for height — 4 ft. 10 in.; time of high water at Beaumaris $2^h\ 35^m$ A.M.; height of high water at Beaumaris 17 ft. 5 in.; time from high water $2^h\ 27^m$; height above half tide 6 ft. 2 in; $2^h\ 27^m$ and 6 ft. 2 in. give correction + 1 ft. 9 in.; half spring range 11 ft. 3 in. + correction 1 ft. 9 in. = Correction for soundings *subt.* 13 ft. 0 in.

6. Standard port of reference, Greenock; constant for time — $0^h\ 19^m$; constant for height — 0 ft. 6 in.; time of high water at Lamlash $1^h\ 44^m$ P.M.; height of high water at Lamlash 8 ft. 9 in.; time from high water $1^h\ 48^m$; height above half tide 3 ft. 9 in.; $1^h\ 48^m$ and 3 ft. 9 in. = correction + 2 ft. 2½ in.; half spring range 5 ft. 0 in. Correction for soundings *subt.* 7 ft. 2½ in.

7. Standard port of reference, Sunderland; constant for time + $0^h\ 49^m$; constant for height + 1 ft. 5 in.; time of high water at Scarbro' $9^h\ 18^m$ P.M.; height of high water at Scarbro' 12 ft. 9 in.; time from high water $1^h\ 51^m$; half spring range 7 ft. 10½ in.; height above half tide 4 ft. 10½ in.; $1^h\ 51^m$ and 4 ft. 10½ in. = correction + 2 ft. 9 in. Correction for soundings *subt.* 10 ft. 7½ in.

8. Standard port of reference, Thurso; constant for time + 2^h 2^m; constant for height — 7 ft. 3 in.; time of high water at Lerwick 10^h 44^m A.M.; height of high water at Lerwick 7 ft. 1 in.; time from high water 2^h 6^m; half spring range 3 ft. 0 in.; height above half tide 4 ft. 1 in.; 2^h 5^m and 4 ft. 1 in. = correction + 1 ft. 10 in.; correction for soundings *subt.* 4 ft. 10 in.

9. Standard port of reference, Londonderry; constant for time — 1^h 37^m; constant for height — 1 ft. 6 in.; time of high water at Coleraine 1^h 6^m P.M.; height of high water at Coleraine 4 ft. 7 in.; time from high water 2^h 27^m; half spring range 3 ft. 1½ in.; height above half tide 1 ft. 5½ in.; 2^h 27^m and 1 ft. 5½ in. = correction + 0 ft. 5 in.; correction for soundings *subt.* 3 ft. 6½ in.

EXAMINATION PAPER—No. I, *Pages* 418-422.

1. Log. 5·861612 = nat. no. 727130. Log. 5·801620 = nat. no. 633316.

2. Log. 2·698971 = nat. no. 500. By *Raper:* log. 2·698970 = 500; log. 0·477121 = nat. no. 3.

3. True Courses.—S. 14° W, 15′ dep. course; S. 28° W., 45′; N. 76° W., 49′; N. 48° W., 38′; N. 85° W., 31′; S. 22° W., 36′; S. 54° W., 41′; S. 42° W., 8′ current course. *Diff. lat.* 77′·7 S., *dep.* 183′·4 W.; *course* S. 67° W.; *dist.* 199′. *Lat. in* 35° 45′ N.; *mid. lat.* 36° 24′; *diff. long.* 228′; *long. in* 12° 48′ W..

4. Green. date Jan. 1^d 6^h 50^m 44^s; red. decl. 22° 59′ 13″ S.; true alt. 60° 12′ 47″. *Latitude* 6° 48′ 0″ N.

By *Raper:* True alt. 60° 12′ 38″. *Latitude* 6° 48′ 9″ N.

5. Log. of diff. long. 2·048016 = *diff. long.* 111′·7.

6. Diff. lat. 219′ S.; mer. diff. lat. 292′; diff. long. 380′ W.; log. tang. of course 10·114401; *course* S. 52° 27′ 38″ W.; log. of distance 2·555607; *distance* 359′·4.

7.	Standard,	Brest	constant	+ 4^h 2^m;	9^h 29^m A.M., and 9^h 46^m P.M.
	„	Portsmouth	„	— 2 41 ;	10 45 A.M., and 11 4 P.M.
	„	Devonport	„	— 0 46 ;	6 35 A.M., and 6 51 P.M.

8. Green. date January 1^d 5^h 23^m 24^s; red. decl. 22° 59′ 31″ S.; log. sine true amp. 9·788530. True amp. E. 37° 54′ 59″ S. *Error of compass* 21° 2′ 29″ E. *Deviation* 2° 49′ 31″ W.

9. Interval 31^d, rate 6^s·3 *gaining*. Interval 28^d 7^h, acc. rate 2^m 58^s·0, Green. date Jan. 29^d 6^h 53^m 49^s, red. decl. 17° 51′ 15″ S., true alt. 13° 47′ 28″, hour-angle 3^h 22^m 41^s, red. eq. time *add* 13^m 24^s·9, mean time at ship 29^d 3^h 36^m 6^s. *Longitude* 49° 25′ 45″ W.

Raper: True alt. 13° 47′ 13″; hour-angle 3^h 22^m 42^s. *Longitude* 49° 25′ 30″ W.

10. Green. date Jan. 15^d 6^h 11^m 12^s, red. decl. 21° 4′ 50″ S., true alt. 55° 18′ 24″, sum of logs. 19·723149, true azimuth N. 93° 16′ 56″ E. *Error of compass* 16° 16′ 56″ E. *Deviation* 8° 26′ 56″ E.

By *Raper:* True alt. 55° 18′ 22″, sine sq. of azimuth 9·723151, true azimuth N. 93° 16′ 57″ E. *Error of compass* 16° 16′ 57″ E. *Deviation* 8° 26′ 57″ E.

Time azimuth: Red. eq. T. *subt.* 9^m 43^s·3; apparent time 9^h 30^m 0^s. *True azimuth* S. 86° 38′ E. *Deviation* 8° 32′ E.

11. Time from noon 16^m 47^s, Green. date January 16^d 14^h 18^m 55^s, red. decl. 20° 49′ 24″ S., true alt. 33° 7′ 1″, nat. no. 2026, nat. cos. mer. zen. dist. 548376, mer. zen. dist. 56° 44′ 40″ N. *Latitude* 35° 55′ 16″ N.

METHOD II.—*Raper:* True alt. 33° 6′ 58″, reduction + 8′ 19″. *Latitude* 35° 55′ 19″ N.

Towson: Aug. I 3′ 5″, aug. decl. 20° 52′ 29″, index 31. Aug. II 5′ 22″. *Latitude* 35° 55′ 8″ N.

12. 1st red. decl. 20° 57′ 14″ S.; eq. T. + $9^m 57^s{\cdot}1$; true alt. *(Norie)* 13° 0′ 53″; latitude 48° 50′; polar dist. 110° 57′ 14″; hour-angle $2^h 25^m 50^s$; longitude 7° 58½′ W. (A). Lat. 49° 30′; hour-angle $2^h 19^m 47^s$. *Longitude* 6° 27½′ W. (A′). 2nd red. decl. 20° 55′ 6″ S.; 2nd red. eq. T. + $10^m 1^s$; 2nd true alt. 14° 10′ 40″. Lat. 48° 50′ gives long. 5° 55½′ W. (B). Lat. 49° 30′ gives long. 7° 36½′ W. (B′). The line of bearing at the first observation trends N.E. ¾ E. (easterly). Sun's azimuth S. 35° E. Ship at the second observation, lat. 49° 40′ N., long. 7° 59′ W. 2nd line of bearing, B B′, N.W. by W. (westerly). Azimuth S. 32° W.

CYCLONES, OR REVOLVING STORMS.

1. In Northern hemisphere centre bears 8 points to the *right* of the direction of the wind; therefore the centre bears S.W.

2. The wind veering to the right, the ship would be in the right-hand semicircle. I would sail her with the wind on her starboard side until in a safe position, and then, if need be, heave-to on the starboard tack. Should the barometer again fall, sail her as before, further out.

3. The change in the direction of the wind might be the reverse of that given in question 2, if the storm was stationary for a time, or one of slow progress, and the ship advancing in the line of the storm's progression faster than the body of the storm. Also, if the ship were in the other semicircle, or if another area of low pressure were following on the heels of the first, as is often the case in the China typhoons, and also in the Bay of Bengal.

4. When a ship is in the line of progression of the centre of a cyclone, there is little or no change in the direction of the wind, which, however, is increasing rapidly in force, with a continually falling barometer, a dangerous sea, and ugly banks of clouds in the direction of the storm fields.

5. When a ship is (*a*) *approaching the centre* the barometer, already low, falls very rapidly, the wind blows furiously, and shifting rapidly (except ship on the line of progression), accompanied with a corresponding high cross sea; (*b*) *receding* from the centre the barometer rises, the wind abates in force, and the sea begins to go down.

6. In answer to this question see Page 411.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. Magnetic course from Cape La Heve to the Needles, N.N.W. ½ W., or N. 25° 19′ W. Compass course N. 22° 19′ W., or N.N.W., distance 95 miles. Deviation 3° W.

II. Magnetic bearing of Cape La Heve S. 17° 4′ E., or S. by E. ½ E. Magnetic bearing of Fecamp S. 62° 4′ E., or S.E. by E. ½ E. Lat. 49° 50½′ N.; long. 0° 16½′ W.

III. 1st magnetic bearing N. 72° 56′ E., or E. by N. ½ N.; 2nd magnetic bearing S. 50° 49′ E., or S.E. ½ E. Lat. 50° 18′ N.; long. 1° 4½′ E.; distance 18 miles.

IV. Magnetic course N. 8° 26′ W.; deviation 6½° W.; compass course N. 2° 11′ W., or N. ½ W.; distance 31 miles.

V. Standard Port for Reference—Portsmouth; constant for time — $1^h 55^m$; constant for height — 6 ft. 0 in.; time of high water, Needles, $10^h 29^m$ A.M.; height at high water, Needles, 8 ft. 0 in.; time from high water $1^h 30^m$; height above half tide 4 ft. 3 in.; $1^h 30^m$ and 4 ft. 3 in. = correction + 3 ft. 0 in.; half spring range 3 ft. 9 in. *Correction* for sounding *subt*. 6 ft. 9 in.

13. Star's decl. 16° 16′ 44″ N., true alt. 52° 30′ 36″. *Latitude* 53° 46′ 8″ N.

Raper: True alt. 52° 30′ 32″. *Latitude* 53° 46′ 12″ N.

The Curve.—Correct magnetic bearing S. 79° W.

Deviations.—15° W.; 0°; 10° E.; 14° E.; 15° E.; 7° E.; 10° W.; 21° W.

Compass courses.—N. 47° W.; N. 27½° E.; S. 79° E.; S. 8½° W.

Magnetic courses.—N. 41½° W.; N. 73° E.; S. 7° E.; S. 67° W.

Bearings, magnetic.—N. 84° E.; N. 14° W.

EXAMINATION PAPER—No. II, *Pages* 425-427.

1. 7·602321 = 40024074. Log. 6·297979 = nat. no. 1986000.

2. 4·477121 = 30000. Log. 5·000004 = nat. no 100001.

3. **True Courses.**—N. 51° E., 18′ dep. course; S. 73° E., 52′; S. 58° E., 43′; N. 57° E., 36′; N. 38° E., 27′; S. 21° E., 24′; S. 40° E., 29′; S. 39° E., 12′ current course. *Diff. lat.* 39′·7 S.; *dep.* 181′·8 E.; *course* S. 78° E., 186′. *Lat. in* 46° 51′ N.; *mid. lat.* 47° 11′; *diff. long. (mid. lat.)* 267½′, or 4° 27½′ E. *Longitude in* 48° 5½′ W.

4. Green. date Jan. $31^d\ 18^h\ 47^m\ 4^s$, or long. in time $5^h\ 12^m\ 56^s$; red. decl. 17° 9′ 34″ S.; true alt. 78° 17′ 52″. *Latitude* 5° 27′ 26″ S.

By *Raper:* True alt. 78° 17′ 51″. *Latitude* 5° 27′ 25″ S.

5. Log. of diff. long. 3·192576 = *diff. long.* 1558′.

6. Diff. lat. 2404′ S.; mer. diff. lat. 3104′; diff. long. 3692′ W.; tang. course 10·075340; *course* S. 49° 56′ 42″ W.; log. of distance 3·572370, *distance* 3736′.

7. Standard, Sunderland, constant + $0^h\ 58^m$; $10^h\ 40^m$ A.M., and $11^h\ 15^m$ P.M.
„ Pembroke, „ — 0 16 ; 11 52 A.M., and No P.M.
„ Leith, „ — 2 21 ; 6 25 A.M., and 7 2 P.M.
„ Devonport, „ — 1 13 ; 10 17 A.M., and 10 51 P.M.
„ Brest, „ — 1 47 ; corr. for long. — 10^m; $8^h\ 9^m$ A.M., $8^h\ 47^m$ P.M.

8. Green. date February $19^d\ 18^h\ 10^m\ 12^s$; red. decl. 11° 0′ 18″ S.; sine 9·290336; true amp. W. 11° 15′ 9″ S. *Error of compass* 19° 41′ 6″ E. *Deviation* 9° 21′ 6″ E.

9. Rate $10^s·8$ *losing*. Interval $30^d\ 9\frac{1}{2}^h$; acc. rate $5^m\ 28^s$; Green. date Feb. $9^d\ 9^h\ 30^m\ 41^s$; red. decl. 14° 32′ 48″ S.; true alt. 9° 14′ 3″; red. eq. time *add* $14^m\ 27^s$; log. 9·321744; hour-angle $3^h\ 38^m\ 4^s$; M.T. ship February $9^d\ 20^h\ 36^m\ 23^s$. *Longitude* 166° 25′ 30″ E.

Raper: True alt. 9° 13′ 52″; sine sq. 9·321825; hour-angle $3^h\ 38^m\ 5^s$. *Long.* 166° 25′ 15″ E.

10. Green. date Feb. $16^d\ 5^h\ 29^m\ 51^s$; red. decl. 12° 15′ 16″ S.; true alt. 7° 15′ 55″; sum of logs. 19·399792; true azimuth S. 60° 8′ 28″ E. *Error* 23° 48′ 28″ W. *Deviation* 1° 11′ 32″ E.

Raper: True alt. 7° 15′ 42″; sine sq. 9·399857 = S. 60° 8′ 46″ E. *Deviation* 1° 11′ 14″ E.

Time azimuth: Red. eq. T. $14^m\ 16^s·4$ *subt.* from M.T.; app. time at ship $7^h\ 53^m\ 19^s$ A.M. Lat. 51° N., decl. 12¼° S., and app. time $7^h\ 53^m$ gives *true azimuth* N. 119° 48′ E. *Deviation* 1° 8′ E.

11. Red. eq. T. $14^m\ 21^s·2$ *subt.* from M.T.; app. time at ship Feb. $14^d\ 23^h\ 31^m\ 12^s$; time from noon $28^m\ 48^s$; red. decl. 12° 44′ 2″ S.; true alt. 46° 31′ 34″ N.; nat. no. 4304; nat. cos. 729993; zen. dist. 43° 6′ 51″ S. *Latitude* 55° 50′ 53″ S.

Method II.—*Raper:* True alt. 46° 31′ 28″; reduction + 21′ 35″. *Latitude* 55° 50′ 59″ S.

Towson: Aug. I + 5′ 53″; index 76; aug. decl. 12° 49′ 55″. Aug. II + 27′ 30″. *Latitude* 55° 50′ 51″ S.

12. 1st red. decl. 16° 41′ 28″ S.; red. eq. T. + $14^m\ 0^s$; true alt. 19° 59′ 43″; lat. 47° 10′ gives hour-angle $2^h\ 7^m\ 48^s$; long. 179° 17½′ E. (A). Lat. 47° 40′ gives hour-angle $2^h\ 3^m\ 5^s$; long. 180° 28½′ E. or 179° 31½′ W. (A′). 2nd red. decl. 16° 37′ 23″ S.; 2nd red. eq. T. + $14^m\ 1^s$; 2nd true alt. 11° 12′ 34″. Lat. 47° 10′ gives hour-angle $3^h\ 26^m\ 37^s$; long. 179° 48¾′ W. (B). Lat. 47° 40′ gives hour-angle $3^h\ 24^m\ 6^s$; long. 179° 33½′ E. (B′). The line of bearing at first observation lies N.E. by E. (easterly). Sun's true bearing S. 32½° E. The ship at second observation in lat. 47° 13½′ N.; long. 179° 53′ W. 2nd line of bearing, B B′, N.W. ½ N. (northerly). Azimuth S. 48° W.

CYCLONES, OR REVOLVING STORMS.

I. Bearing of centre, East.

II. Left-hand semicircle. Run, keeping the wind, if possible, on the starboard quarter; and when the barometer rises, if necessary, to keep the ship from going too far from her proper course, heave-to on the port tack (see page 408).

III. See answer to same question, Paper I.

IV. See answer to same question, Paper I.

V. See answer to same question, Paper I.

VI. See answer to same question, page 412.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. Magnetic course from Needles to Cape Barfleur S. ½ W. or S. 5° 38′ W.; compass course South, distance 59 miles; deviation 5½° E.

II. Magnetic bearing of Christchurch N. 11° 23′ W. or N. by W.; magnetic bearing of St. Catherine's S. 59° 11′ E. or S.E. by E. ½ E.; Latitude 50° 38½′ N.; Longitude 1° 42′ W.

III. 1st magnetic bearing S. 67° 38′ E. or E.S.E.; 2nd magnetic bearing N. 56° 8′ E. or N.E. by E.; Latitude 50° 21′ N.; Longitude 1° 35′ W.; distance 17 miles.

IV. Magnetic course S. by E. or S. 11° 15′ E.; deviation 2° W. Compass course S. 9° 15′ E.; distance 36 miles.

V. Standard Port for Reference—Brest; constant for time + $5^{h}\,4^{m}$; constant for height — 1 ft. 0 in; time of high water Cape Barfleur $4^{h}\,29^{m}$ P.M.; height at high water Cape Barfleur 12 ft. 0 in.; time from high water $1^{h}\,54^{m}$; height above half tide 3 ft. 6 in.; $1^{h}\,54^{m}$ and 3 ft. 6 in. = correction + 1 ft. 11 in.; half spring range 8 ft. 6 in. Correction for soundings *subt.* 10 ft. 5 in.

13. Star's decl. 5° 30′ 37″ N.; true alt. 77° 14′ 26″. *Latitude* 18° 16′ 11″ N.

Raper: True alt. 77° 14′ 16″. *Latitude* 18° 16′ 21″ N.

The Curve.—Correct magnetic bearing S. 39° E.

Deviations.—5° W.; 19° E.; 23° E.; 13° E.; 4° E.; 8° W.; 22° W.; 24° W.

Compass courses.—N. 43° E.; N. 68° W.; N.W. by W.; N. 83° E.

Magnetic courses.—S. 82° W.; N. 52° E.; S. 35° W.; S.S.E.

Bearings, magnetic.—S. 80½° W.; S. 1½° E.

EXAMINATION PAPER—No. III, *Pages* 427-429.

1. 6·370772 = 2348400; 5·316682 = 207339·71.

2. 1·875495 = 75·075; 2·694089 = 494·4125.

3. **True Courses.**—S. 70° E., 17′ dep. course; S. 37° W., 21′; S. 24° W., 20′; N. 62° W., 24′; N. 64° W., 26′; S. 77° E., 19′; S. 28° E., 18′; N. 54° E., 21′ current course. *Diff. lat.* 26′·1 S.; *dep.* 5′·3 W.; *course* S. 11° W.; *dist.* 27′. *Lat. in* 61° 34′ N.; *mid. lat.* 61° 47′; *diff. long.* 11′ W. *Long. in* 149° 49′ E.

4. Green. date, March $20^{d}\,11^{h}\,33^{m}\,12^{s}$, or long. in time $11^{h}\,33^{m}\,12^{s}$; red. decl. 0° 1′ 21″ N; true alt. 89° 53′ 28″. *Latitude* 0° 5′ 11″ S.

Raper: True alt. 89° 53′ 22″. *Latitude* 0° 5′ 17″ S.

5. Log. of diff. long. 3·619156 = *diff. long.* 4161.

6. Diff. lat. 688′ N.; mer. diff. lat. 786′; diff. long. 3625′ W.; tang. 10·663885; *course* N. 77° 45′ 58″ W.; log. of *distance* = 3·511451; *distance* 3247′.

7. Standard, Brest constant + $6^{h}\,19^{m}$; no A.M. and $0^{h}\,2^{m}$ P.M.
„ Brest „ + 5 31; $11^{h}\,14^{m}$ A.M., and 11 32 P.M.
„ Portsmouth „ — 2 31; 11 13 A.M., and 11 32 P.M.
„ Harwich „ — 2 51; 11 20 A.M., and 11 39 P.M.
„ Thurso „ + 2 2; 0 9 A.M., and 0 28 P.M.
„ Liverpool „ — 0 55; 0 7 A.M., and 0 25 P.M.

8. Green. date, March $6^{d}\,14^{h}\,47^{m}\,28^{s}$; red. decl. 5° 25′ 41″ S.; sine amp. 9·188477; true amp. W. 8° 52′ 42″ S.; *correction* 7° 59′ 48″ E.; *deviation* 16° 0′ 12″ W.

9. Rate $5^{s}{\cdot}8$ *gaining*; interval $89^{d}\,23^{h}$; acc. rate $8^{m}\,41^{s}{\cdot}7$; Green. date, March $30^{d}\,22^{h}\,53^{m}\,12^{s}{\cdot}5$; red. decl. 4° 7′ 31″ N.; true alt. 29° 19′ 56″; hour-angle 3° 56′ 53″; red. eq. time *add* $4^{m}\,18^{s}$; mean time ship March $30^{d}\,20^{h}\,7^{m}\,25^{s}$. *Longitude* 41° 27′ 0″ W.

Raper: True alt. 29° 19′ 45″; hour-angle $3^{h}\,56^{m}\,54^{s}$. *Longitude* 41° 27′ 15″ W.

10. Green. date, March $9^d\,9^h\,43^m\,5^s$; red. decl. 4° 20′ 41″ S.; true alt. 18° 6′ 51″; sum of logs. 19·605706; true azimuth N. 78° 51′ 26″ E. *Correction* 7° 28′ 26″ E.; *deviation* 3° 21′ 34″ W.

Raper: 9·605727; true azimuth N. 78° 51′ 34″ E. *Correction* 7° 28′ 34″ E.; *deviation* 3° 21′ 26″ W.

True azimuth: Red. eq. T. $10^m\,37^s{\cdot}4$ *subt.* from M.T.; app. time at ship $19^h\,23^m$. *True azimuth* S. 101° 11′ E. *Deviation* 3° 24′ W.

11. Red. eq. T. $6^m\,11^s$ *subt.* from M.T.; app. time at ship March $25^d\,0^h\,10^m\,10^s$; time from noon $10^m\,10^s$; red. decl. 1° 42′ 31″ N.; true alt. 71° 21′ 43″; nat. no. 924; nat. cos. mer. zen. dist. 948480 = 18° 28′ 18″ N. *Latitude* 20° 10′ 49″ N.

Method II.—*Raper:* True alt. 71° 21′ 37″ + 10′ 7″. *Latitude* 20° 10′ 47″ N.

Towson: Aug. I, + 0′ 7″; index no. 13. Aug. II, + 10′ 14″. *Latitude* 20° 10′ 41″ N.

12. 1st red. decl. 2° 45′ 22″ N.; 1st eq. T. + $5^m\,22^s{\cdot}2$; true alt. 36° 49′ 14″; lat. 51° 30′ gives hour-angle $1^h\,41^m\,36^s$; long. 180° 39½′ W. or 179° 20½′ E. (A); lat. 51° 0′ gives hour-angle $1^h\,46^m\,30^s$; long. 181° 53′ W. or 178° 7′ E. (A′). 2nd red. decl. 2° 51′ 25″ N.; 2nd red. eq. T. + $5^m\,17^s$; true alt. 15° 23′ 34″; lat. 51° 30′ gives long. 179° 19¾′ W. (B); lat. 51° 0′ gives long. 179° 6¾′ W. (B′). The line of bearing trends S.W. by W. Azimuth S. 34° E. Ship at time of second observation, lat. 51° 33′ N., long. 179° 21′ W. 2nd line of bearing B B′, S. by E. ½ E. (easterly). Azimuth S. 75° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. Magnetic course from East Point of Guernsey to Berry Head, N. by W. ½ W., or N. 16° 53′ W. Compass course N. 11° 53′ W., or N. by W., dist. 65 miles. Dev. 5° W.

II. Magnetic bearing of Hanois S. 23° W., or S.S.W. Magnetic bearing of Casquets S. 87° E., or E. ½ S. Latitude 49° 40′ N.; longitude 2° 41′ W.

III. 1st magnetic bearing, Casquets, N. 57° E., or N.E. by E.; 2nd magnetic bearing S. 68° E., or E.S.E.; latitude 49° 45′ N.; longitude 2° 43½′ W.; distance 13½ miles.

IV. Magnetic course N.W. ⅝ N., or N. 37° 58′ W.; compass course N. 39° 40′ W., or N.W. ½ N., distance 21 miles. Deviation 1° 42′ E.

V. Standard Port for Reference—Devonport; constant for time + $0^h\,17^m$; constant for height — 1 ft. 9 in.; time of high water, Torbay, $0^h\,2^m$ P.M.; height of high water, Torbay, 9 ft. 6 in.; time from high water $3^h\,40^m$; half spring range 6 ft. 9 in.; height above half tide 2 ft. 9 in; $3^h\,40^m$ and 2 ft. 9 in. = correction — 0 ft. 11 in. Correction for sounding *subt.* 5 ft. 10 in.

13. Star.—Arcturus' decl. 19° 46′ 9″ N.; true alt. 36° 7′ 27″. *Latitude* 34° 6′ 24″ S.

Raper: True alt. 36° 7′ 22″. *Latitude* 34° 6′ 29″ S.

The Curve.—Correct magnetic bearing S. 70° E.

Deviations.—3° W.; 20° E.; 25° E.; 25° E.; 1° E.; 24° W.; 25° W.; 18° W.

Compass courses.—N. 35° E.; S. 82° W.; N. 85½° W.; S. 49° E.

Magnetic courses.—S.E. by S.; N. 84½° E.; N. 86° W.; N.W. by N.

Bearings, magnetic.—N. 87½° W.; N. 78½° E.

EXAMINATION PAPER—No. IV, *Page* 429-431.

1. Log. 6·602331 = 4002500. Log. 4·861964 = 72772.

2. Log. 2·008970 = 102·087. Log, 2·033424 = 108.

3.—True Courses.—S., 19′ dep. course; S. 59° W., 58′; N. 11° W., 15′; S. 28° E., 9′; S. 82° W., 50′; N. 72° E., 12′; S. 58° W., 22′; S. 62° W. 42′, current course. *Diff. lat.* 76′·8 S.; *dep.* 142′·3 W.; *course* S. 62° W.; *dist.* 162′. *Lat. in* 51° 29′ S.; *diff. long.* 225′ W. *Longitude in* 183° 25′ W., or 176° 35′ E.

4. Green. date, April $1^d\,5^h\,31^m\,8^s$; red. decl. 4° 37′ 11″ N.; true alt. 48° 55′ 26″. *Lat.* 45° 41′ 45″ N.

Raper: True alt. 48° 55′ 19″. *Latitude* 45° 41′ 50″ N.

5. Log. of diff. long. 3·774704 = *Diff. long.* 5952·56.

6. Diff. lat. 5649′; mer. diff. lat. 6462′; diff. long. 299′ W.: tang. course 8·665304; *course* N. 2° 38′ 57″ W.; *log. dist.* 3·752436; *dist.* 5655.

7. Standard,	Brest	+ $2^h 45^m$;	no A.M.,	and $0^h 26^m$ P.M.
„	Hull	+ 0 1 ;	no A.M.,	and 0 27 P.M.
„	Thurso	— 1 56 ;	$0^h 12^m$ A.M.,	and 0 53 P.M.
„	Pembroke	+ 0 4 ;	11 49 A.M.,	and no P.M.
„	Weston-super-mare	+ 0 2 ;	no A.M.,	and 0 22 P.M.
„	Waterford	+ 0 44 ;	11 49 A.M.,	and no P.M.

Green. date, April 27^d 23^h 18^m 50^s; red. decl. 14° 7′ 42″ N.; log. sine 9·492912; true amplitude W. 18° 7′ 34″ N. *Error* 15° 37′ 26″ W.; *deviation* 3° 32′ 34″ E.

9. Rate $11^s·3$ *losing*; interval 71^d 4^h; acc. rate 13^m $24^s·2$; Green. date, April 15^d 4^h 35^m 52^s; red. decl. 9° 49′ 14″ N.; red. eq. time *subt.* 0^m 0^s; true alt. 26° 37′ 25″; hour-angle 2^h 59^m 3^s; M.T. ship April 15^d 2^h 59^m 3^s. *Longitude* 24° 12′ 15″ W.

Raper: True alt. 26° 37′ 20″; sine sq. 9·161331; hour-angle 2^h 59^m 3^s. *Long.* 24° 12 15″ W.

10. Red. decl. 10° 30′ 4″ N.; true alt. 42° 20′ 40″; sum of logs. 19·447862; true azimuth S. 63° 57′ 14″ W. *Error* 26° 2′ 46″ W.; *deviation* 6° 12′ 46″ W.

Raper: True alt. 42° 20′ 34″; sine sq. 9·447890; true azimuth S. 63° 57′ 23″ W. *Error of compass* 26° 2′ 37″ W.; *deviation* 6° 12′ 37″ W.

Time azimuth: Red. eq. T. 0^m 28^s *add* to M.T.; app. time at ship April 17^d 2^h 50^m 13^s P.M. *True azimuth* N. 116° 11′ W.; *error of compass* 26° 10′ W. *Deviation* 6° 21′ W.

11. Red. eq. T. 0^m 47^s *add* to M.T.; app. time at ship 23^h 31^m 19^s; time from noon 28^m 41^s; red. decl. 10° 58′ 51″ N.; true alt. 54° 20′ 16″; nat. no. 5310, nat. cos. mer. zen. dist. 817778 = 35° 8′ 13″ N. *Lat.* 46° 7′ 4″ N.

METHOD II.—*Raper:* True alt. 54° 20′ 12″; Red. + 31′ 37″. *Latitude* 46° 7′ 2″ N.

Towson: Aug. I, + 5′ 5″; index no. 76. Aug. II, + 36′ 28″. *Latitude* 46° 7′ 12″ N.

12. 1st red. decl. 6° 27′ 35″ N.; eq. T. + 2^m 29^s; true alt. 45° 18′ 16″; lat. 50° 20′ gives hour-angle 0^h 40^m 48^s; long. 8° 32′ W. (A); lat. 50° 50′ gives hour-angle 0^h 25^m 43^s; long. 12° 18′ 15″ W. (A′). 2nd red. decl. 6° 30′ 30″ N.; eq. T. + 2^m $26^s·3$; true alt. 25° 2′ 12″; lat. 50° 20′ gives long. 7° 13¾′ W.; lat. 50° 50′ gives long. 7° 32½′ W. The line of bearing at first observation W. by N. Azimuth S. 11¼° W. Ship at the time of second observation in lat. 59° N., long. 7° 7½′ W. 2nd line of bearing, B B′, N. by W. ¼ W. westerly. Azimuth S. 69° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. Magnetic course, West. Dev. 27° E. Compass course S. 63° W., or S.W. by W. ¾ W., distance 82 miles.

II. Magnetic bearing, Christchurch, N. 10½° E., or N. by E.; magnetic bearing, Anvil Point, N. 62° W., or N.W. by W. ½ W. Latitude 50° 34′ N.; longitude 1° 44′ W.

III. 1st magnetic bearing, St. Catherine's, S. 57° E., or S.E. by E.; 2nd magnetic bearing S. 80° E., or E. ¾ S.; latitude 50° 30½′ N.; longitude 2° 3′ W.; distance 29 miles.

IV. Magnetic course, West. Deviation 27° E. Compass course S. 63° W., or S.W. by W. ¾ W., distance 12 miles.

V. Standard Port for Reference—Portsmouth; constant for time — 4^h 40^m; constant for height — 6 ft. 0 in.; time of high water, Portland Breakwater, 7^h 44^m A.M.; height at high water, Portland, 8 ft. 0 in.; time from high water 3^h 45^m; height above half tide 4 ft. 7½ in.; 3^h 45^m and 4 ft. 7½ in. = correction — 1 ft. 9 in.; half spring range 3 ft. 4½ in. Correction for sounding *subt.* 1 ft. 7½ in.

13. Star.—Spica's decl. 10° 34′ 23″ S. *Latitude* 58° 34′ 57″ N.

Raper: True alt. 20° 50′ 28″ S. *Latitude* 58° 35′ 9″ N.

The Curve.—Correct magnetic bearing South.

Deviations.—4° W.; 27° W.; 36° W.; 30° W.; 7° E.; 33° E.; 35° E.; 22° E.

Compass courses.—S. 40° E.; S. 27° W.; N. 5° E.; S. 74° E.

Magnetic courses.—N. 17° W.; N. 14½° E.; N. 74° W.; N. 4° W.

Bearings, magnetic.—Dev. 35° W.; N. 80° W.; S. 32½° W.

EXAMINATION PAPER—No. V, *Pages* 431-433.

1. 6·041523 = nat. no. 1100331; 4·735413 = nat. no. 54376·75.

2. 2·826661 = nat. no. 670·905; 7·657058 = nat. no. ·00454002.

3. **True Courses.**—S. 65° E., 23′ dep. course; S. 6° E., 56′; S. 14° W., 17′; N. 80° W., 13′; East, 37′; S. 44° W., 31′; N. 26° E., 17′; N. 85° E., 48′ current course. Diff. lat. 82′·4 S., dep. 80′ 6 E.; course S. 44° E., dist. 115′. *Lat. in* 65° 24′ S., *mid. lat.* 64° 43′, *diff. long.* 189′ E. *Long. in* 178° 30′ W.

4. Green. date May $8^{d}\ 7^{h}\ 1^{m}\ 8^{s}$; red. decl. 17° 9′ 18″ N.; true alt. 76° 14′ 12″. *Lat.* 3° 23′ 30″ N.

Raper: True alt. 76° 14′ 3″. *Latitude* 3° 23′ 21″ N.

5. Log. of diff. long. 3·699628 = *Diff. long.* 5007·57.

6. Diff. lat. 732′ S.; mer. diff. lat. 881′; diff. long. 1098′ W.; log. tang. 10·095626; *course* S. 51° 15′ 27″ W.; *log. of distance* 3·068060; *distance* 1169·6.

7. Standard,	Greenock	constant	— $0^{h}56^{m}$;	$11^{h}21^{m}$ A.M., and	$11^{h}40^{m}$ P.M.
„	Liverpool	„	— 0 1 ;	11 28 A.M., and	11 46 P.M.
„	Sunderland	„	— 1 4 ;	2 27 A.M., and	2 45 P.M.
„	Brest	„	+ 2 18 ;	6 12 A.M., and	6 30 P.M.
„	Dover	„	— 0 27 ;	10 54 A.M., and	11 14 P.M.

8. Green. date May $20^{d}\ 16^{h}\ 6^{m}\ 24^{s}$; red. decl. 20° 6′ 31″ N.; log. sine 9·693622, true amp. E. 29° 35′ 45″ N. *Error of compass* 12° 35′ 30″ E.; *deviation* 19° 14′ 30″ W.

9. Interval 36^{d}; rate $4^{s}{\cdot}9$ *gaining*; Interval $50^{d}\ 21^{h}$; acc. rate — $4^{m}\ 9^{s}$; Green. date May $21^{d}\ 20^{h}\ 59^{m}\ 16^{s}$; red. decl. 20° 21′ 9″ N.; red. eq. T. *subt.* $3^{m}\ 35^{s}{\cdot}9$; true alt. 32° 19′ 31″; sum of logs. 9·451651; hour-angle $4^{h}\ 17^{m}\ 4^{s}$; mean time at ship May $21^{d}\ 19^{h}\ 39^{m}\ 20^{s}$. *Longitude* 19° 59′ 0″ W.

Raper: True alt. 32° 19′ 21″; hour-angle $4^{h}\ 17^{m}\ 5^{s}$. *Longitude* 19° 59′ 15″ W.

10. Green. date May $25^{d}\ 9^{h}\ 53^{m}\ 51^{s}$; red. decl. 21° 1′ 5″ N.; true alt. 40° 54′ 26″; sum of logs. 19·632974; true azimuth S. 81° 53′ 44″ W. or N. 98° 6′ 16″ W. *Error* 20° 23′ 44″ E.; *deviation* 9° 53′ 44″ E.

Raper: True alt. 40° 54′ 22″; sine sq. 9·632984; true azimuth S. 81° 53′ 48″ W. or N. 98° 6′ 12″ W. *Error* 20° 23′ 48″ E.; *deviation* 9° 53′ 48″ E.

Time Azimuth: Red. eq. T. $3^{m}\ 17^{s}{\cdot}7$ *add* to M.T.; app. time ship May $25^{d}\ 3^{h}\ 33^{m}\ 5^{s}$ P.M.; *true azimuth* N. 98° 10′ W.; *error* 20° 20′ E.; *deviation* 9° 50′ E.

11. Red. eq. T. $3^{m}\ 47^{s}{\cdot}1$ *add* to M.T.; time from noon $25^{m}\ 23^{s}$; red. decl. 17° 41′ 43″ N.; true alt. 43° 39′ 55″; nat. no. 5142; mer. zen. dist. 45° 55′ 34″ S. *Latitude* 28° 13′ 51″ S.

METHOD II.—*Raper:* True alt. 43° 39′ 49″; Red. + 24′ 37″. *Latitude* 28° 13′ 51″ S.

Towson: Aug. I + 6′ 7″; index 63½. Aug. II + 18′ 29″. *Latitude* 28° 13′ 46″ S.

12. 1st red. decl. 21° 44′ 18″ N.; 1st red. eq. T. — $2^{m}\ 46^{s}{\cdot}7$; 1st true alt. 23° 52′ 16″; lat. 50° 0′ gives hour-angle $5^{h}\ 13^{m}\ 15^{s}$; long. 9° 19¼′ W. (A). Lat. 50° 30′ gives hour-angle $5^{h}\ 13^{m}\ 34^{s}$; long. 9° 24′ W. (A′). 2nd red. decl. 21° 46′ 49″ N.; 2nd red. eq. T. *subt.* $2^{m}\ 44^{s}$; 2nd true alt. 56° 56′ 35″; lat. 50° 0′ gives hour-angle $1^{h}\ 27^{m}\ 32^{s}$; long. 10° 34¼′ W. (B). Lat. 50° 30′ gives hour-angle $1^{h}\ 23^{m}\ 35^{s}$; long. 11° 33½′ W. (B′). The line of bearing at the first observation trends N. ½ W. Sun's true azimuth N. 84° E. 2nd line of bearing, B B′, N.W. ½ W.; azimuth S. 39° W. Ship at the second observation in lat. 50° 2′ N., long. 10° 38½′ W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. Magnetic course from Smalls to Saltees N.W. ⅜ N., or N. 41° W. Deviation 3° E. Compass course N. 44° W., or N.W., distance 41½ miles.

II. Magnetic bearing, St. David's Head, N. 81° 45′ E.; or E. ¾ N. Magnetic bearing, Smalls, S. 30° 45′ E., or S.S.E. ¾ E. Latitude 51° 45′ N.; longitude 5° 44′ W.

III. 1st magnetic bearing, St. Ann's Head, N. 73° 19′ E., or E. by N. ½ N.; 2nd magnetic bearing, S. 78° 34′ E., or E. by S.; latitude 51° 37′ N.; longitude 5° 44½′ W; distance 21½ miles.

IV. Magnetic course N.N.W. ¾ W., or N. 30° 56′ W. Deviation 1° W. Compass course N. 29° 56′ W., or N.N.W. ⅝ W., distance 16½ miles.

V. Standard Port for Reference—Pembroke; constant for time — $0^h 12^m$; constant for height 0; time of high water, Smalls, $11^h 57^m$ A.M.; height of high water, Smalls, 15 ft. 2 in.; time from high water $2^h 15^m$; half spring range 10 ft. 6 in.; height above half tide 4 ft. 8 in.; $2^h 15^m$ and 4 ft. 8 in. = correction + 1 ft. 9 in. Correction for sounding *subt.* 12 ft. 3 in.

13. Star.—Star's decl. 10° 34′ 23″ S. *Latitude* 30° 28′ 7″ S.

Raper: True alt. 70° 6′ 16″. *Latitude* 30° 28′ 7″ S.

The Curve.—Correct magnetic bearing N. 87° E.

Deviations.—3° W.; 15° W.; 23° W.; 22° W.; 2° E.; 24° E.; 29° E.; 13° E.

Compass courses.—N. 45½° E.; S. 71½° W.; S. 49° E.; S. 39½° W.

Magnetic courses.—N. 20½° W.; N. 46° E.; S. 76½° E.; S. 61° W.

Bearings, magnetic.—S. 8° E.; S. 85° W.

EXAMINATION PAPER—No. VI, *Pages* 433-435.

1. 5·729117 = nat. no. 535940·7; 6·793616 = 6217500.

2. 2·111111 = nat. no. 129·155; 1·995636 = 99·0.

3. True Courses.—S. 73° E., 23′ dep. course; S. 75° E., 17′; S. 33° E., 22′; S. 1° W., 24′; S. 61° E., 25′; N. 69° W., 18′; S. 43° W., 17′; N. 11° E., 16′ current course. *Diff. lat.* 55′·9 S., *dep.* 46′·6 E.; *course* S. 40° E.; *dist.* 73′. *Lat. in* 55° 16′ N.; *diff. long.* (Mercator) 82′·8 E.; *long. in* 134° 17′ W. *Diff. long.* (*by mid. lat.*) 83′ E.; *long. in* 134° 17′ W.

4. Green. date, May $31^d\ 17^h\ 34^m\ 52^s$; red. decl. 22° 0′ 54″ N.; true alt. 75° 49′ 26″. *Latitude* 7° 50′ 20″ N. (*Norie*).

Raper: True alt. 75° 49′ 17″. *Latitude* 7° 50′ 11″ N.

5. Log. of diff. long. 2·319176 = *Diff. long.* 208′·53.

6. Diff. lat. 2181′ S.; mer. diff. lat. 2301′; diff. long. 3038′ W.; tangent course 10·120671; *course* S. 52° 51′ 34″ W.; *log. distance* 3·557783; *distance* 3612′·3.

7. Standard, Holyhead — $3^h 10^m$; $0^h 23^m$ A.M.; $0^h 55^m$ P.M.
„ Weston-super-mare — 0 4; 11 55 A.M.; no P.M.
„ Brest + 2 42; no A.M.; 0 1 P.M.
„ Portsmouth — 0 5; 4 40 A.M.; 5 8 P.M.
„ Brest + 7 53; corr. for long. — 8^m; $4^h 34^m$ A.M.; $5^h 4^m$ P.M.

8. Green. date June $21^d\ 13^h\ 34^m\ 48^s$; red. decl. 23° 27′ 7″ N.; sine of true amplitude 9·898928; true amplitude W. 52° 24′ 27″ N. *Error* 46° 1′ 48″ W.; *deviation* 6° 28′ 12″ E.

9. Interval 29^d, daily rate $8^s·3$ *losing*, interval $45^d\ 11^h$, accumulated rate $6^m\ 17^s$, Green. date June $14^d\ 10^h\ 45^m\ 16^s$, red. decl. 23° 17′ 32″ N., true alt. 28° 49′ 40″, red. eq. time 0, hour-angle $3^h\ 49^m\ 6^s$, M.T. ship June $14^d\ 3^h\ 49^m\ 6^s$. *Longitude* 104° 2′ 30″ W.

By *Raper:* True alt. 28° 49′ 35″, hour-angle $3^h\ 49^m\ 7^s$. *Longitude* 104° 2′ 15″ W.

10. Green. date June $14^d\ 17^h\ 6^m\ 54^s$; red. decl. 23° 18′ 14″ N.; true alt. 12° 49′ 21″; logs. 19·247967; true azimuth N. 49° 45′ 32″ E. *Error* 31° 48′ 13″ W.; *deviation* 7° 8′ 13″ W.

By *Raper:* True alt. 12° 49′ 9″; sine sq. 9·248026; *true azimuth* N. 49° 45′ 45″ E.; *error* 31° 48′ W.; *deviation* 7° 8′ W.

Time azimuth: Red. eq. T. $0^m\ 3^s·4$ *subt.* from M.T.; app. time ship $8^h\ 23^m\ 27^s$; *true azimuth* N. 49° 48′ E.; *error* 31° 46′ W.; *deviation* 7° 6′ W.

11. Time from noon 37^{m} 26^{s}; Green. date June 4^{d} 14^{h} 14^{m} 8^{s}; red. decl. 22° 30′ 5″ N.; true alt. 50° 3′ 22″; nat. no. 5779; mer. zen. dist. 39° 25′ 31″ N. *Latitude* 61° 55′ 36″ N.

Method II. + 31′ 15″. True alt. (*Norie*) 50° 3′ 22″; *latitude* 61° 55′ 28″ N. True alt. (*Raper*) 50° 3′ 19″; *latitude* 61° 55′ 31″ N.

Towson: Beyond the limits of the Table.

12. 1st red. decl. 23° 13′ 14″ N.; 1st red. eq. T. + 3^{m} 12^{s}·7; 1st true alt. 62° 58′ 38″; lat. 49° 40′ gives hour-angle 0^{h} 28^{m} 18^{s}; long. 177° 41¾′ E. (A). Lat. 50° 0′ gives hour-angle 0^{h} 18^{m} 29^{s}; long. 180° 9′ E. or 179° 51′ W. (A′) 2nd red. decl. 23° 12′ 30″ N.; 2nd eq. T. + 3^{m} 15^{s}; 2nd true alt. 30° 13′ 32″; lat. 49° 40′ gives long. 180° 15½′ E. or 179° 44½′ W. (B). Lat. 50° 0′ gives long. 180° 16′ E. or 179° 44′ W. (B′). The line of bearing at the first observation trends E. by N. Sun's azimuth S. 11° E. 2nd line of bearing B B′ N. 1° E. Azimuth N. 89° W. Ship at the second observation in lat. 50° 6½′ N., long. 179° 44′ W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course W. by N. ¼ N., or N. 77° W. Deviation 12° E. Compass course N. 71° W., or W. by N. ¾ N., distance 52 miles.

II. True bearing, Cape Barfleur, S. 32° 45′ E., or S.S.E. ⅞ E.; true bearing of Cape La Hague S. 75° 34′ W., or W. by S. ¼ S. Latitude 49° 49½′ N.; longitude 1° 23′ W.

III. 1st true bearing N. 39° E., or N.E. ½ N.; 2nd true bearing N. 78° 23′ E., or E. by N. Latitude 49° 35½′ N.; Longitude 0° 31′ W.; distance 27 miles.

IV. True course N.W. ¼ N., or N. 42° 11′ W.; compass course N. 73° 45′ W., or W. by N. ½ N. Deviation 13° E. Distance 39 miles.

V. Standard Port for Reference—Brest; time constant + 5^{h} 4^{m}; height constant — 1 ft. 0 in.; time of high water, Cape Barfleur, 0^{h} 16^{m} A.M.; height at high water 14 ft. 6 in.; time from high water 2^{h} 12^{m}; height above half tide 6 ft. 0 in; 2^{h} 12^{m} and 6 ft. 0 in. = correction + 2 ft. 5 in.; half spring range 8 ft. 6 in. Correction for sounding *subt.* 10 ft. 11 in.

13. **Star.**—Star's decl. 28° 17′ 49″ N.; true alt. (*Norie*) 48° 33′ 45″. *Latitude* 13° 8′ 26″ S.

Raper: True alt. 48° 33′ 40″. *Latitude* 13° 8′ 31″ S.

The Curve.—Correct magnetic bearing S. 79° W.

Deviations.—12° W.; 0°; 17° E.; 21° E.; 12° E.; 4° E.; 18° W.; 24° W.

Compass courses.—N.W. by N.; S. 70° W.; N. 27½° E.; S. 1½° E.

Magnetic courses.—N.W. by W.; S. 61° W.; S. 17° W.; S. 40½° E.

Correct magnetic bearing.—N. 11° E.; N. 87½° W.

EXAMINATION PAPER—No. VII, *Pages* 435-437.

1. 5·805908 = 639600; 3·775928 = 5969·36.

2. 2·537819 = 345·0; 3·096778 = 1249·62.

3. **True Courses.**—S. 25° E., 17′; N. 73° E., 22′; S. 79° E., 24′; N. 80° W., 26′; N. 85° E., 17′; N. 58° E., 40′; S. 68° E., 51′; N. 62° W., 9′ current course. *Diff. lat.* 1′·3 S., *dep.* 116′·4 E., *course* S. 89½° E., *dist.* 116′·4. *Lat. in* 51° 24′ N., *mid. lat.* 51° 24′, *long.* 187° E. *Long. in* 182° 3′ E., or 177° 57′ W.

4. Green. date July 26^{d} 0^{h} 49^{m} 16^{s}; red. decl. 19° 27′ 33″ N.; true alt. 15° 46′ 12″, *Latitude* 54° 46′ 15″ S.

Raper: True alt. 15° 46′ 3″. *Latitude* 54° 46′ 24″ S.

5. Log. of diff. long. 2·633861 = *diff. long.* 430′·4 nearly.

6. Diff. lat. 745′ S.; mer. diff. lat. 1042′; diff. long. 1292′ W.; log. tang. 10·093394; *course* S. 51° 6′ 49″ W.; *log. distance* 3·074350, *distance* 1186′·7,

7. Standard, Brest constant — $0^h 45^m$; no A.M., $0^h 18^m$ P.M.
„ Brest „ — 0 5 ; $0^h 26^m$ A.M., 0 58 P.M.
„ Brest „ — 0 29 ; 0 2 A.M., 0 34 P.M.
„ Hull „ — 0 29 ; 2 36 A.M., 3 7 P.M.
Brest, constant + $4^h 48^m$, corr. for long. — 12^m; $5^h 7^m$ A.M.; $5^h 39^m$ P.M.

8. Green. date July $12^d 6^h 36^m 32^s$; red. decl. 21° 57′ 24″ N.; sine amp. 9·631153; true amp. W. 25° 19′ 21″ N. *Correction* 5° 38′ 6″ E.; *deviation* 16° 58′ 6″ E.

9. Interval 8^d, rate $5^s·55$ *losing.* interval $32^d 22^h$, accumulated rate + $3^m 2^s·7$. Green. date July $16^d 21^h 58^m 19^s$, red. decl. 21° 14′ 24″ N., true alt. 13° 31′ 23″, red. eq. T. $5^m 50^s$ *add*; hour-angle $3^h 51^m 13^s$, M.T. ship $17^d 3^h 57^m 3^s$. *Longitude* 89° 41′ 0″ E.

Raper: True alt. 13° 31′ 7″; hour-angle $3^h 51^m 14^s$. *Longitude* 89° 41′ 15″ E.

10. Green. date July $4^d 1^h 53^m 22^s$; red. decl. 22° 53′ 26″ N.; true alt. 12° 21′ 31″; sum of logs. 19·205902; true azimuth N. 47° 15′ 32″ E. *Error* 27° 59′ 32″ E.; *deviation* 10° 39′ 32″ E.

Raper: True alt. 12° 21′ 21″; sine sq. 9·205962; true azimuth N. 47° 15′ 45″ E. *Error* 27° 59′ 45″ E.; *deviation* 10° 39′ 45″ E.

Time azimuth: Red. eq. T. $4^m 5^s$ *subt.* from M.T.; app. time ship $8^h 34^m 57^s$ A.M.; *true azimuth* S. 132° 42′ E.; *error* 28° 2′ E.; *deviation* 10° 42′ E.

11. Time from noon $25^m 20^s$; Green. date July $30^d 18^h 52^m 32^s$; red. decl. 18° 21′ 4″ N.; true alt. 26° 24′ 19″; nat. no. 4090; mer. zen. dist. 63° 19′ 58″ S. *Latitude* 44° 58′ 54″ S.

METHOD II. Red. + 15′ 43″. *Latitude* 44° 58′ 54″ S.

Raper: True alt. 26° 24′ 13″. *Latitude* 44° 59′ S.

Towson: Aug. I + 6′ 22″; index 63. Aug. II + 9′ 27″. *Latitude* 44° 58′ 48″ S.

12. 1st red. decl. 23° 8′ 20″ N.; 1st red. eq. T. + $3^m 28^s·4$; 1st true alt. 30° 12′ 33″; lat. 51° 0′ N. gives hour-angle $4^h 40^m 4^s$; long. 5° 21½′ W. (A). Lat. 51° 40′ N. gives hour-angle $4^h 40^m 4^s$; long. 5° 21½′ W. (A′). 2nd red. decl. 23° 7′ 57″ N.; 2nd red. eq. T. + $3^m 29^s·48$; 2nd true alt. 51° 11′ 38″. Lat. 51° 0′ gives hour-angle $2^h 20^m 4^s$; long. 4° 51½′ W. (B). Lat. 51° 40′ N. gives hour-angle $2^h 17^m 15^s$; long. 4° 9½′ W. (B′). The line of bearing at the first observation trends North. Sun's azimuth East. The ship's position at second observation is lat. 51° 10′ N., long. 4° 41′ W. 2nd line of bearing B B′ N.E. by N. Azimuth S. 56° E.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. Magnetic course, Dungeness to Cape Cayeux, S. ¾ E., or S. 8° 26′ E. Deviation 0° 45′ W. Compass course S. 7° 41′ E., or S. ¾ E., distance 48 miles.

II. Magnetic bearing of Dungeness N. 14° W., or N. by W. ¼ W.; magnetic bearing, Varne lightvessel, N. 67° 30′ E., or E.N.E. Latitude 50° 49′ N.; longitude 1° 3′ E.

III. 1st magnetic bearing, Beachy Head, N. 57° W., or N.W. by W.; 2nd magnetic bearing North. Latitude 50° 24′ N.; longitude 0° 24′ E.; distance 22 miles.

IV. Magnetic course S.S.E. ¼ E., or S. 25° 19′ E. Deviation 7° 37′ W. Compass course S. 17° 42′ E., or S. by E. ⅝ E., distance 18½ miles.

V. Standard Port for Reference—Dover; time constant — $0^h 27^m$; height constant + 3 ft. 6 in.; time of high water, Dungeness, $11^h 17^m$ A.M.; height at high water 23 ft. 0 in.; time from high water $1^h 55^m$; height above half tide 12 ft. 1½ in.; $1^h 55^m$ and 12 ft. 1½ in. = correction + 6 ft. 6 in.; half spring range 10 ft. 10½ in. Correction for sounding *subt.* 17 ft. 4½ in.

13. **Star.**—Star's decl. 26° 10′ 48″ S.; true alt. 70° 5′ 46″. *Latitude* 46° 5′ 2″ S.

Raper: True alt. 70° 5′ 44″. *Latitude* 46° 5′ 4″ S.

The Curve.—Correct magnetic bearing N. 89° W.

Deviations.—1° E.; 19° E.; 21° E.; 9° E.; 4° W.; 11° W.; 19° W.; 16° W.

Compass courses.—N. 51° E.; S. 81½° E.; S. 23½° W.; North.

Magnetic courses.—S. 70° W.; N. 6° E.; N. 80½° E.; S. 33° E.

Bearings, magnetic.—N. 75° E.; N. 66½° E.

EXAMINATION PAPER—No. VIII, *Pages* 437-439.

1. 5·889986 = 776221·4; 3·983651 = 9630·555.

2. 2·676541 = 474·833; 5·291146 = 195500.

3. True Courses.—N. 78° E., 23′ dep. course; N. 84° E., 54′; East, 55′; East, 66′; N. 83° E., 22′; N. 79° E., 43′; N. 85° E., 32′; S. 85° E., 66′ current course. *Diff. lat.* 18′3 N.; *dep.* 358′·8 E.; *course* N. 87° E.; *dist.* 360′. *Lat. in* 0° 28′ N.; *diff. long.* 359′ E. *Longitude in* 174° 6′ W.

4. Green. date Aug. $11^d\ 17^h\ 51^m\ 12^s$; red. decl. 15° 4′ 58″ N.; true alt. 42° 50′ 17″. *Lat.* 32° 4′ 45″ S.

Raper: True alt. 42° 50′ 6″. *Latitude* 32° 4′ 56″ S.

5. Log. of diff. long. 2·805956 = *Diff. long.* 639′·7.

6. Diff. lat. 297′ N.; mer. diff. lat. 1007′; diff. long. 303′ E.; tangent 9·478414; *course* N. 16° 44′ 46″ E.; *log. dist.* 2·491576; *distance* 3102′.

7. Standard, Brest — $0^h 26^m$; $11^h 22^m$ A.M., and midnight
„ Devonport — 1 13; 11 51 A.M., and no P.M.
„ Greenock + 5 14; no A.M., and 0 37 P.M.
„ Weston-super-mare — 2 10; no A.M., and 0 13 P.M.
„ Brest — 1 51; 9 57 A.M., and 10 35 P.M.

8. Green. date August $18^d\ 0^h\ 22^m\ 40^s$; red. decl. 13° 7′ 43″ N.; sine 9·625874; true amp. W. 24° 59′ 44″ N. *Correction* 65° 0′ 16″ W.; *deviation* 27° 20′ 16″ W.

9. Interval 7^d, rate $6^s{\cdot}6$ *losing*, interval $16^d\ 20\frac{1}{2}^h$, accumulated rate + $1^m\ 51^s$, Green. date Aug. $6^d\ 20^h\ 32^m\ 47^s$, red. decl. 16° 29′ 51″ N., true alt. 24° 17′ 1″, red. eq. T. $5^m\ 35^s$ *additive*, hour-angle $4^h\ 25^m\ 44^s$, M.T. ship $7^d\ 4^h\ 31^m\ 19^s$. *Longitude* 119° 40½′ E.

Raper: True alt. 24° 16′ 57″; hour-angle $4^h\ 25^m\ 44^s$. *Longitude* 119° 40½′ E.

10. Green. date Aug. $31^d\ 11^h\ 18^m\ 53^s$; red. decl. 8° 30′ 18″ N.; true alt. 24° 58′ 53″; sum of logs. 19·357277; true azimuth N. 56° 59′ 46″ W. *Error* 9° 11′ 1″ W.; *deviation* 19° 1′ 1″ W.

Raper: True alt. 24° 58′ 45″; sine sq. logs. 9·357314 = N. 56° 59′ 57″ W. *Error* 9° 11′ 12″ W.; *deviation* 19° 1′ 12″ W.

Time azimuth: Red. eq. T. $0^m\ 6^s{\cdot}1$ *subt.* from M.T.; app. time ship $3^h\ 21^m\ 26^s$; *true azimuth* S. 122° 57′ W.; *error* 9° 14′ W.; *deviation* 19° 4′ W.

11. Time from noon $35^m\ 15^s$; Green. date August $10^d\ 13^h\ 0^m\ 10^s$; red. decl. 15° 26′ 28″ N.; true alt. 34° 48′ 15″; nat. no. 8837; mer. zen. dist. 54° 34′ 37″ S. *Latitude* 39° 8′ 9″ S.

METHOD II.—*Reduction* + 37° 19′. *Latitude* 39° 7′ 58″ S.

Raper: Red. + 37′ 19″. True alt. 34° 48′ 11″. *Latitude* 39° 8′ 2″ S.

Towson: Aug. I + 10′ 37″; index 90. Aug. II + 26° 38′. *Latitude* 39° 8′ 2″ S.

12. 1st red. decl. 15° 38′ 4″ N.; 1st red. eq. T. $5^m\ 10^s{\cdot}9$ *add*; 1st true alt. 38° 27′ 40″; lat. 49° 40′ gives hour-angle $3^h\ 12^m\ 15^s$; long. 3° 55¼′ W. (A). Lat. 50° 0′ gives hour-angle $3^h\ 11^m\ 20^s$; long. 3° 41½′ W. (A′). 2nd red. decl. 15° 33′ 36″ N.; 2nd red. eq. T. $5^m\ 9^s$ *add*; 2nd true alt. 40° 20′ 59″; lat. 49° 40′ gives long. 2° 58¼′ W. (B). Lat. 50° 0′ gives long. 3° 14¼′ W. (B′). The line of bearing at first observation trends N.N.E. Sun's azimuth S. 67½° E. The position of ship at second observation is lat. 50° 9′ N., long. 3° 22′ W. 2nd line of bearing B B′ N.N.W. ¼ W. (westerly). Azimuth S. 63° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from Hartland Point to Trevose Head S.W. by S., or S. 33° 45′ W.; variation 21° W.; deviation 25° 30′ E.; compass course S. 29° 15′ W., or S.S.W. ¼ W. (westerly), distance 34 miles.

II. True bearing of Hartland Point N. 83° 15′ E. or E. ⅝ N.; true bearing of Lundy Island N. 27° E., or N.N.E. ⅜ E.; latitude 51° N.; longitude 4° 48′ W.

III. 1st true bearing of Hartland Point E. by S. ⅜ S., or S. 74° 15′ E.; 2nd true bearing E. by N. ⅜ N., or N. 72° E.; latitude 50° 56′ N.; longitude 4° 59′ W.; distance 18 miles.

IV. True course S. 33° 51′ W., or S.W. by S.; deviation 25° 50′ E. Compass course S. 29° 20′ W., or S.S.W. ⅝ W.; distance 24 miles.

V. Standard Port for Reference—Weston-super-Mare; constant for time — $1^h 41^m$; constant for height — 16 ft. 6 in; time of high water, Padstow, $10^h 47^m$ P.M.; height at high water, Padstow, 11 ft. 6 in.; time from high water $3^h 48^m$; height above half tide 1 ft. 3 in.; $3^h 48^m$ and 1 ft. 3 in. = correction — 0 ft. 6 in.; half spring range 10 ft. 3 in. Correction for sounding *subt.* 9 ft. 9 in.

13. **Star.**—Star's decl. 8° 34′ 32″ N.; true alt. 66° 48′ 17″. *Latitude* 14° 37′ 11″ S. *(Norie).*
„ „ „ 66 48 13 „ 14 37 15 S. *(Raper).*

The Curve.—Correct magnetic bearing North.

Deviations.—14° W.; 13° E.; 22° E.; 19° E.; 8° E.; 9° W.; 18° W.; 21° W.

Compass courses.—N. 36° W.; S. 87° E.; S. 7° E.; N. 85½° W.

Magnetic courses.—N. 58° E.; S. 40° W.; N. 6° W.; S. 77° E.

Bearings, magnetic.—S. 88° E.; S. 4½° W.

EXAMINATION PAPER—No. IX, *Pages* 439-441.

1. 4·147399 = 14041·04. 7·888411 = ·007734.

2. 6·854294 = ·00071498. 1·602689 = 40·058.

True Courses.—N. 48° E., 22′ dep. course; N. 84° E., 42′; S. 89° E., 54′; S. 26° W., 37′; N. 8° E., 33′; S. 78° E., 34′; N. 89° E., 42′; N. 83° E., 66′ current course. *Diff. lat.* 29′·2 N.; *dep.* 241′·3 E.; *course* N. 85½° E.; *dist.* 242′. *Latitude in* 60° 28′ N.; *diff. long.* 487′·1 E. *Longitude in* 6° 1′ E.

4. Green. date Sept. $22^d\ 15^h\ 45^m$; red. decl. 0° 5′ 9″ N.; true alt. 90° 0′ 5″. *Latitude* 0° 5′ 14″ N.

Raper: True alt. 89° 59′ 57″. *Latitude* 0° 5′ 6″ N.

5. Log. of diff. long. 2·785262 = *diff. long.* 609′·9.

6. Diff. lat. 3607′ S.; mer. diff. lat. 3798′; diff. long. 4007′ E.; tang. 10·023264; *course* S. 46° 32′ E.; *log. distance* 3·719604; *distance* 5243′·3.

7. Standard, Brest	$+2^h 59^m$;	$1^h 27^m$ A.M., and	$2^h 13^m$ P.M.
„ Harwich	$-0\ 33$;	5 59 A.M., and	6 43 P.M.
„ Dover	$+1\ \ 6$;	6 56 A.M., and	7 35 P.M.
„ Devonport	$-0\ 29$;	no A.M., and	0 8 P.M.
„ Dover	$-0\ 19$;	5 31 A.M., and	6 10 P.M.
„ Leith	$-2\ 30$;	7 14 A.M., and	7 56 P.M.

8. Green. date September $30^d\ 6^h\ 33^m\ 40^s$; red. decl. 2° 52′ 59″ S.; sine 8·987100; true amp. W. 4° 44′ 22″ S. *Error* 41° 18′ 7″ W.; *deviation* 10° 50′ 7″ W.

9. Interval 15^d, rate 2^s·6 *gaining*, interval $19^d\ 15\frac{1}{2}^h$, accumulated rate — $0^m\ 51^s$, Green. date August $31^d\ 15^h\ 35^m\ 8^s$, red. decl. 8° 26′ 25″ N., red. eq. T. $0^m\ 3^s$ +., true alt. 62° 25′ 6″, hour-angle $1^h\ 51^m\ 38^s$, M.T. ship Sept. $1^d\ 1^h\ 51^m\ 41^s$. *Long.* 154° 8′ 15″ E.

Raper: True alt. 62° 24′ 55″; hour-angle $1^h\ 51^m\ 39^s$. *Longitude* 154° 8′ 30″ E.

10. Green. date September $16^d\ 1^h\ 29^m\ 54^s$; red. decl. 2° 38′ 44″ N.; true alt. 29° 41′ 59″; sum of logs. 19·703180; true azimuth S. 90° 33′ 30″ E. *Error* 3° 53′ 30″ W. *Deviation* 12° 13′ 30″ W.

Raper: True alt. 29° 41′ 53″; sine sq. 9·703180; true azimuth S. 90° 33′ 29″ E. *Error* 3° 53′ 29″ W.; *deviation* 12° 13′ 29″ W.

Time azimuth: Red. eq. T. $5^m\ 10^s$·2 *add* to M.T.; app. time at ship $8^h\ 8^m\ 28^s$; *true azimuth* N. 89° 34′ E.; *error of compass* 3° 46′ W.; *deviation* 12° 6′ W.

11. Time from noon $16^m\ 41^s$, Green. date September $22^d\ 12^h\ 27^m\ 55^s$, red. decl. 0° 8′ 21″ N., true alt. 62° 9′ 19″, nat. no. 2348, mer. zen. dist. 27° 33′ 19″ S. *Latitude* 27° 24′ 58″ S.

Method II. + 17° 23′. *Latitude* 27° 24′ 57″ S.

Raper: True alt. 62° 9′ 12″. *Latitude* 27° 25′ 4″.

Towson: Aug. I, + 2″, index 35. Aug. II, + 12′ 36″. *Latitude* 27° 24′ 42″ S.

12. 1st red. decl. 5° 28′ 0″ N.; 1st red. eq. T. — 2^m 36^s; 1st true alt. 11° 9′ 42″; lat. 47° 50′ gives hour-angle 5^h 17^m 35^s; long. 33° 59¼′ E. (A). Assumed lat. 47° 10′ gives hour-angle 5^h 17^m 52^s; long. 33° 55½′ E. (A′). 2nd red. decl. 5° 23′ 59″ N.; 2nd red. eq. T. — 2^m 39^s·7; 2nd true alt. 45° 56′ 32″; lat. 47° 50′; long. 35° 38′ E. (B). Lat. 47° 10′ gives long. 33° 10½′ E. (B′). The line of bearing at the first observation trends S. ½ W. (west'ly). Azimuth S. 86° E. 2nd line of bearing, B B′, W.S.W. Azimuth S. 22½° E. Ship at second observation in lat. 47° 30′ N., long. 34° 26′ E.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. Magnetic course from St. Goven's Head to Hartland Point, S. 2° 49′ E., or S. ¼ E. Deviation 1° 45′ E. Compass course S. 4° 34′ E., or S. ⅜ E., distance 37½ miles.

II. Magnetic bearing of Lundy Island S. 1° 4′ E., or S. ⅛ E.; magnetic bearing, Morte Point, S. 46° 4′ E., or S.E. ⅛ E. Latitude 51° 20′ N.; longitude 4° 47′ W.

III. 1st magnetic bearing, Hartland Point, S.E. ¾ E., or S. 34° 49′ E.; 2nd magnetic bearing S.E. ¾ E., or S. 54° 30′ E. Latitude 51° 4½′ N.; longitude 4° 51′ W.; dist. 12½ miles.

IV. Magnetic course S. 16° 52′ E., or S. by E. ½ E. Deviation 4° 15′ W. Compass course S. 12° 37′ E., or S. by E. ⅛ E., distance 38½ miles.

V. Standard Port for Reference—Weston-super-Mare; constant for time — 1^h 39^m; constant for height — 10 ft. 0 in.; time of high water, Lundy Island, 10^h 41^m A.M.; height of high water 17 ft. 2 in.; time from high water 4^h 29^m; height above half tide 3 ft. 8 in.; half spring range 13 ft. 6 in.; 4^h 29^m and 3 ft. 8 in. = correction — 2 ft. 7 in. Correction for sounding *subt.* 10 ft. 11 in.

13. **Star.**—Star's decl. 19° 46′ 23″ N., true alt. 86° 31′ 18″. *Latitude* 16° 17′ 41″ N. (*Norie*).
„ „ 86 31 17 „ 16 17 40 N. (*Raper*).

The Curve.—Correct magnetic bearing S. 88° W.

Deviations.—2° E., 20° E., 22° E., 9° E., 4° W., 12° W., 20° W., 17° W.

Compass courses.—West, N. 2° E., N. 59½° E., S. 61½° E.

Magnetic courses.—N. 2° E., S. 17° W., S. 57½° E., N. 72° E.

Bearings, magnetic.—S. 84½° E., N. 76½° W.

EXAMINATION PAPER—No. X, *Pages* 441-443.

1. 7·447213 = 28003548, 3·524617 = 3346·7.

2. 1·936010 = 86·30, 2·735031 = 543·288.

3. **True Courses.**—S. 75° E., 36′ dep. course; S. 8° E., 43′; S. 15° W., 19′; N. 69° E., 50′; N. 77° E., 21′; S. 5 E., 6′; S. 51° E., 22′; N. 88° E, 48′ current course. *Diff. lat.* 65′·8 S.; *dep.* 168′·7 E.; *course* S. 69° E.; *dist.* 181′. *Lat. in* 58° 43′ N.; *mid. lat.* 59° 16′; *diff. long.* 330′ E. *Long. in* 38° 24 W.

4. Green. date Oct. 20^d 10^h 1^m 40^s, red. decl. 10° 28′ 45″ S., true alt. 50° 11′ 14″. *Lat.* 50° 17′ 31″ S.

Raper: True alt. 50° 11′ 9″. *Latitude* 50° 17′ 36″ S.

5. Log. of diff. long. 2·019277 = *diff. long.* 104′·5.

6. Diff. lat. 140′ N.; mer. diff. lat. 142′; diff. long. 46′ E.; tang. course 9·510470; *course* N. 17° 57′ E.; log. of distance 2·167797, *distance* 147′·1.

7. Standard,	Brest,	constant	— 2^h 0^m;	no A.M., and	0^h 15^m P.M.
„	London,	„	— 2 19;	10^h 1^m A.M., and	10 25 P.M.
„	Leith,	„	— 2 55;	9 53 A.M., and	10 16 P.M.
„	Sunderland,	„	— 1 4;	0 17 A.M., and	0 45 P.M.
„	Liverpool,	„	— 0 19;	9 9 A.M., and	9 31 P.M.

8. Green. date Oct. 8^d 11^h 13^m 48^s; red. decl. 6° 2′ 35″ S.; true amp. E. 6° 22′ 58″ S. *Error* 9° 11′ 43″ E. *Deviation* 11° 1′ 43″ E.

9. Interval 7^d; rate 2^s·4 *losing*; interval 22^d 12^h; accumulated rate 0^m 54^s; Green. date October 30^d 12^h 0^m 22^s; red. decl. 13° 56′ 42″ S.; true alt. 28° 42′ 58″; hour-angle 2^h 46^m 13^s; red. eq. T. 16^m 15^s *subt.*; M.T. ship Oct. 30^d 2^h 29^m 58^s. *Longitude* 142° 36′ 0″ W.

Raper: True alt. 28° 42′ 50″; hour-angle 2^h 46^m 14^s. *Longitude* 142° 35′ 45″ W.

10. Green. date Sept. $30^{d}\ 18^{h}\ 43^{m}\ 48^{s}$; red. decl. 3° 4′ 58″ S.; true alt. 14° 7′ 3″; sum of logs. 19·690416; true azimuth N. 88° 52′ 56″ W. *Error* 4° 30′ 26″ W. *Deviation* 12° 10′ 26″ W.

Raper: True alt. 14° 6′ 51″; sine sq. 9·690425; true azimuth N. 88° 53′ 1″ W. *Deviation* 12° 10′ 31″ W.

Time azimuth: Red. eq. T. $10^{m}\ 13^{s}$·0 *add* to M.T.; app. time at ship $5^{h}\ 4^{m}\ 13^{s}$; *true azimuth* S. 91° 17′ W.; *error* 4° 20½′ W.; *deviation* 12° 0½′ W.

11. Time from noon $17^{m}\ 8^{s}$; Green. date Oct. $2^{d}\ 1^{h}\ 17^{m}\ 8^{s}$; red. decl. 3° 34′ 26″ S.; true alt. 47° 39′ 40″ N.; nat. no. 2191; mer. zen. dist. 42° 9′ 8″ N. *Latitude* 38° 34′ 42″ N.

Method II.—*Red.* + 11′ 18″; *lat.* 38° 34′ 36″ N. (*Norie*) 38° 34′ 45″ N. (*Raper*).

Towson: Aug. I + 35″; index 36. Aug. II + 10′ 28″. *Latitude* 38° 34′ 51″ N.

12. 1st red. decl. 3° 10′ 13″ S.; 1st red. eq. T. — $10^{m}\ 17^{s}$·4; 1st true alt. 23° 29′ 11″; lat. 50° 30′; hour-angle $3^{h}\ 3^{m}\ 59^{s}$; long. 50° 48′ W. (A). Lat. 51° 0′ gives hour-angle $3^{h}\ 1^{m}\ 27^{s}$; long. 50° 10′ W. (A′). 2nd red. decl. 3° 15′ 48″ S.; 2nd red. eq. T. — $10^{m}\ 22^{s}$; true alt. 25° 39′ 34″; lat. 50° 30′ gives long. 49° 44½′ W. (B). Lat. 51° gives long. 50° 29½′ W. (B′). The line of bearing at first observation trends N.E. ½ N. Sun's azimuth S. 50½° E. Ship at second observation in lat. 50° 53′ N.; long. 50° 18½′ W. 2nd line of bearing, B B′, N.W. ½ N. Azimuth S. 48° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from Fecamp to St. Catherine's N.W. ¾ W. or N. 53° 26′ W.; deviation 0° 34′ E.; compass course N.W. ¾ N. or N. 36° W., distance 80 miles.

II. True bearing Owers Light N. 55° 42′ E. or N.E. by E. True bearing St. Catherine's Light N. 31° 30′ W. or N.N.W. ¾ W. Lat. 50° 26′ N. Long. 1° 10′ W.

III. 1st true bearing Owers Light N. 24° 45′ E. or N.N.E. ¼ E.; 2nd true bearing N. 78° 11′ E. or E. by N. Lat. 50° 34′ N. Long. 1° 15½′ W. Distance 22 miles.

IV. True course N.W. ⅜ N. or N. 40° 47′ W. Deviation 4° W. Compass course N. by W. ⅝ W. or N. 18° 47′ W., distance 35 miles.

V. Standard Port for Reference—Brest; constant for time + $6^{h}\ 57^{m}$; constant for height + 4 ft. 2 in.; time of high water Fecamp $6^{h}\ 44^{m}$ A.M.; Height of high water Fecamp 19 ft. 2 in.; time from high water $2^{h}\ 44^{m}$; height above half tide 7 ft. 5 in.; $2^{h}\ 44^{m}$ and 7 ft. 5 in. = corr. + 1 ft. 0 in.; half spring range 11 ft. 9 in. Correction for sounding *subt.* 12 ft. 9 in.

13. **Star.**—Star's decl. 14° 36′ 12″ N.; true alt. 54° 6′ 7″. *Latitude* 50° 30′ 5″ N. (*Norie*).
„ „ „ 54 6 3 „ 50 30 9 N. (*Raper*).

The Curve.—Correct magnetic bearing N. 71° W.

Deviations.—8° E.; 30° E.; 30° E.; 19° E.; 6° W.; 24° W.; 32° W.; 25° W.

Compass courses.—N. 39° E.; S. 82° W.; N. 84° E.; N. 1½° W.

Magnetic courses.—S. 81½° W.; S. 17° W.; N. 2½° E.; S. 9° E.

Bearings, magnetic.—S. 67½° E.; S. 25½° W.

EXAMINATION PAPER—No. XI, *Pages* 443-445.

1. 2·639859 = 436·375; 0·452105 = 2·832.

2. 1·999489 = 99·88; 5·212511 = 163121·4.

3. **True Courses.**—N. 42° E., 16′ dep. course; N. 14° E., 17′; S. 45° E., 19′; S. 87° W., 31′; S. 63° E., 17′; S. 5° E., 19′; S. 56° W., 25′; S. 88° E., 22′ current course. *Diff. lat.* 51′·8 S.; *dep.* 6′·1 W.; *course* S. 7° W.; *dist.* 52′. *Lat. in* 51° 8′ N.; *diff. long.* 10′. *Long. in* 119° 50′ E.

4. Green. date November $14^{d}\ 18^{h}\ 39^{m}\ 16^{s}$; red. decl. 18° 25′ 52″ S.; true alt. 67° 57′ 49″. *Latitude* 40° 28′ 3″ S.

Raper: True alt. 67° 57′ 40″. *Latitude* 40° 28′ 12″ S.

5. Log. of diff. long. 2·294311 = *diff. long.* 196′·9.

6. Diff. lat. 290′ N.; mer. diff. lat. 1033′; diff. long. 246′ E.; tang. 9·376835; *course* N. 13° 23′ 42″ E.; log. of *distance* = 2·474376; *distance* 298′·1.

7. Standard, Dover constant + $1^h 13^m$; $6^h 39^m$ A.M., and $7^h 16^m$ P.M.
„ Devonport „ — 0 17 ; noon
„ Hull „ — 1 3 ; no A.M., and 0 20 P.M.
„ Weston-super-Mare „ — 1 12 ; no A.M., and 0 9 P.M.

8. Green. date, Nov. $9^d\ 12^h\ 20^m\ 44^s$; red. decl. 17° 0′ 25″ S.; true amp. E. 33° 43′ 56″ S.; *correction* 42° 12′ 19″ W.; *deviation* 58° 42′ 19″ W.

9. Interval 12^d; rate $1^s{\cdot}2$ *losing*; interval $36^d\ 3^h$; accumulated rate $43^s{\cdot}3$; Green. date Nov. $30^d\ 2^h\ 48^m\ 52^s$; red. decl. 21° 40′ 27″ S.; red. eq. T. $11^m\ 10^s{\cdot}1$ *subt.*; true alt. 39° 47′ 8″; hour-angle 3° 42′ 0″; M.T. ship Nov. $29^d\ 20^h\ 6^m\ 50^s$. *Longitude* 100° 30′ 30″ W.

Raper: True alt. 39° 47′ 6″; hour-angle $3^h\ 42^m\ 0^s{\cdot}5$. *Longitude* 100° 30′ 37″·5 W.

10. Green. date Nov. $15^d\ 10^h\ 46^m\ 27^s$; red. decl. 18° 36′ 20″; true alt. 43° 55′ 7″; sum of logs. 19·512988; true azimuth N. 69° 36′ 50″ W. or S. 110° 23′ 10″ W. *Error* 11° 53′ 10″ E. *Deviation* 19° 43′ 10″ E.

Raper: True alt. 43° 55′ 2″; sine sq. 9·513003; true azimuth N. 69° 36′ 55″ W. *Deviation* 19° 43′ 5′ E.

Time azimuth: Red. eq. T. $15^m\ 13^s$ *add* to M.T.; app. time at ship $3^h\ 1^m\ 56^s$; *true azimuth* S. 110° 25′ W.; *error* 11° 55′ E.; *deviation* 19° 45′ E.

11. Time from noon $39^m\ 26^s$; Green. date Nov. $13^d\ 2^h\ 36^m\ 2^s$; red. decl. 17° 59′ 41″ S.; true alt. 56° 11′ 50″; nat. no. 8864; mer. zen. dist. 32° 52′ 44″ S. *Latitude* 50° 52′ 25″ S.

METHOD II.—Red. + 56′ 8″, true alt. 56° 11′ 50″, *latitude* 50° 51′ 43″ S., *Noris.* True alt. 56° 11′ 46″, *latitude* 50° 51′ 47″ S., *Raper.*

Towson: Hour-angle exceeds limits of Table.

12. 1st red. decl. 21° 12′ 25″ S.; 1st red. eq. T. — $12^m\ 7^s{\cdot}4$; 1st true alt. 14° 1′ 55″; lat. 46° 0′ gives hour-angle $2^h\ 36^m\ 21^s$; long. 179° 48′ 30″ E. (A). Lat. 46° 40′ gives hour-angle $2^h\ 31^m\ 10^s$; long. 178° 53¾′ W. (A′). 2nd red. decl. 21° 14′ 22″ S.; 2nd red. eq. T. — $12^m\ 4^s$; 2nd true alt. 18° 22′ 47″; lat. 46° 0′ gives long. 178° 54′ W. (B). Lat. 46° 40′ gives long. 179° 5½′ E. (B′). The line of bearing at the first observation trends N.E. ¾ E. Azimuth S. 36½° E. Ship at second observation in lat. 46° 22½′ N., long. 180° W. 2nd line of bearing, B B′, N.W. by W. ¾ W. (nearly). Azimuth S. 26° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from Cape de la Heve to Nab Lightvessel N.N.W. ¾ W. or N. 30° 56′ W.; deviation 6° W. Compass course N. ⅝ W. or N. 6° 56′ W., distance 82½ miles.

II. True bearing of Owers Light N. 70° 13′ E. or E. by N. ¾ N. True bearing of Nab Lightvessel N. 19° 47′ W. or N. by W. ¾ W. Lat. 50° 35½′ N. Long. 0° 55½′ W.

III. 1st true bearing Owers Light N. 46° 19′ E. or N.E. ⅛ E.; 2nd true bearing S. 77° 26′ E. or E. by S. ⅛ S. Latitude 50° 41½′ N. Longitude 0° 59′ W. Dist. 11¾ miles.

IV. True course N. ⅞ W. or N. 10° 58′ W. Deviation 8° 30′ W. Compass course N. 15° 32′ E. or N. by E. ¾ E., distance 14½ miles.

V. Standard Port for Reference—Portsmouth; constant for time — $0^h\ 41^m$; height constant 0; time of high water Bembridge $11^h\ 33^m$ A.M.; height of high water Bembridge 13 ft. 6 in.; time from high water $1^h\ 21^m$; height above half tide 6 ft. 6 in.; $1^h\ 21^m$ and 6 ft. 6 in. = correction + 4 ft. 11 in.; half spring range 7 ft. 0 in. Correction for soundings *subt.* 11 ft. 11 in.

13. **Star.**—Star's decl. 30° 13′ 7″ S., true alt. 59° 36′ 2″, *latitude* 60° 37′ 5″ S., *Noris.* True alt. 59° 35′ 58″, *latitude* 60° 37′ 9″ S., *Raper.*

The Curve.—Correct magnetic bearing S. 89° W.

Deviations.—1° E., 19° E., 21° E., 9° E., 3° W., 11° W., 19° W., 16° W.

Compass courses.—N. 85° W., N. 45½° W., N. 86° E., South.

Magnetic courses.—S. 77° W., N. 58° W., S. 49° E., N. 56° E.

Bearings, magnetic.—S. 76° W., S. 56° E.

EXAMINATION PAPER—No. XII, *Pages* 445-447.

1. 7·010519 = 10245165·1; 7·367405 = ·00233026.

2. 1·168317 = 14·7339; 2·096910 = 125.

3. True Courses.—S. 45° W., 16′ dep. course; N. 73° E., 15′; S. 49° W., 23′; S. 43° E., 15′; N. 47° W., 24′; N. 80° E., 22′; S. 53° W., 12′; S. 14° E., 6′ current courses. *Diff. lat.* 25′·8 S.; *dep.* 8′·2 W.; *course* S. 18° W.; *dist.* 27′. *Lat. in* 49° 34′ N.; *diff. long.* 13′ W. *Longitude in* 40° 13′ W.

4. Green. date Dec. $31^{d}\ 8^{h}\ 15^{m}$; red. decl. 23° 4′ 57″ S.; true alt. 67° 20′ 49″; *latitude* 0° 25′ 46″ S.

Raper: True alt. 67° 20′ 45″. *Latitude* 0° 25′ 42″ S.

5. Log. of diff. long. 2·346353 = *diff. long.* 222′.

6. Diff. lat. 4766′ S.; mer. diff. lat. 5205′; diff. long. 3735′ W.; tang. course 9·855870; *course* S. 35° 39′ 45″ W.; log. of distance 3·768350; *distance* 5866′.

7. Standard, Queenstown, constant — $0^{h}59^{m}$; $0^{h}\ 9^{m}$ A.M., and $0^{h}42^{m}$ P.M.
„ Sligo „ — 0 21 ; 1 31 A.M., and 1 59 P.M.
„ Queenstown „ — 1 19 ; no A.M., and 0 22 P.M.
„ Galway „ + 1 35 ; 2 39 A.M., and 3 7 P.M.
„ Londonderry „ — 1 37 ; 3 4 A.M., and 3 27 P.M.
„ Pembroke „ — 0 30 ; 1 42 A.M., and 2 15 P.M.

8. Green. date Dec. $28^{d}\ 4^{h}\ 10^{m}\ 49^{s}$; red. decl. 23° 17′ 2″ S.; true amp. E. 35° 15′ 30″ S. *Correction* 9° 56′ 45″ E.; *deviation* 5° 33′ 15″ W.

9. Interval 12^{d}, rate $5^{s}\cdot7$ *losing*; interval $42^{d}\ 16^{h}$; acc. rate $4^{m}\ 3^{s}\cdot1$. Green. date Dec. $24^{d}\ 15^{h}\ 48^{m}\ 36^{s}\cdot5$; red. decl. 23° 24′ 59″ S.; red. eq. time *add* $0^{m}\ 5^{s}$, true alt. 40° 54′ 8″, hour-angle 3° 41′ 17″. *Longitude* 178° 11′ 22″·5 E.

Raper: True alt. 40° 54′ 2″; hour-angle $3^{h}\ 41^{m}\ 17^{s}$. *Longitude* 178° 11′ 22″·5 E.

10. Green. date Dec. $27^{d}\ 4^{h}\ 40^{m}\ 10^{s}$, red. decl. 23° 19′ 50″ S., true alt. 20° 27′ 7″, sum of logs. 19·362368, true azimuth S. 57° 21′ 45″ E. *Error of compass* 12° 57′ 0″ E. *Deviation* 5° 37′ 0″ E.

By *Raper:* True alt. 20° 26′ 54″, log. sine sq. 9·362393 = S. 57° 21′ 52″ E. *Error of compass* 12° 56′ 53″ E. *Deviation* 5° 36′ 53″ E.

Time azimuth: Red. eq. T. $1^{m}\ 20^{s}\cdot9$, *subt.* from M.T.; app. time at ship $7^{h}\ 58^{m}\ 50^{s}$ A.M.; *true azimuth* N. 122° 12′ E. *Error* 12° 31′ E. *Deviation* 5° 11′ E.

11. Time from noon $30^{m}\ 40^{s}$, Green. date Dec. $4^{d}\ 1^{h}\ 30^{m}$, red. decl. 22° 15′ 24″ S., true alt. 60° 7′ 18″, nat. no. 5105, zen. dist. 29° 17′ 9″ S. *Latitude* 51° 32′ 33″ S.

METHOD II. + 35′ 29″, true alt. 60° 7′ 18″, *latitude* 51° 32′ 37″ S., *Norie.* True alt. 60° 7′ 14″, *latitude* 51° 32′ 41″ S., *Raper.*

Towson: Exceeds limits of Table.

12. 1st Green. date Dec. $24^{d}\ 22^{h}\ 11^{m}\ 2^{s}$; decl. 23° 24′ 33″ S.; eq. T. + $0^{m}\ 12^{s}\cdot7$ true alt. 9° 14′ 59″; lat. 46° 30′ gives hour-angle $2^{h}\ 58^{m}\ 51^{s}$; long. 17° 25′ W. (A); lat 46° 0′ gives hour-angle $3^{h}\ 2^{m}\ 9^{s}$; long. 18° 14½′ W. (A′). 2nd Green. date Dec. $25^{d}\ 3^{h}\ 15^{m}$; decl. 23° 24′ 14″ S.; eq. T. + $0^{m}\ 19^{s}$; true alt. 15° 12′ 14″; lat. 46° 30′ gives hour-angle $1^{h}\ 57^{m}\ 35^{s}$; long. 19° 16½′ W. (B); lat. 46° 0′ gives hour-angle $2^{h}\ 2^{m}\ 56^{s}$; long. 17° 56½′ W. (B′). The line of bearing at the first observation trends S.W. ½ W. Sun's azimuth S. 42° E. Ship at the second observation in lat. 45° 46½′ N., long. 17° 19′ W. 2nd line of bearing, B B′, S.E. by E. ½ E. (nearly). Azimuth S. 29° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from A to St. Catherine's, W. ⅛ S., or S. 88° 36′ W. Deviation 20° E. Compass course S. 86° 36′ W., or W. ½ S., dist. 73 miles.

II. True bearing of Beachy Head, N. 85° 11′ W., or W. ⅜ N.; true bearing of Dungeness, N. 32° 56′ E., or N.E. by N. Lat. 50° 42½′ N., long. 0° 46′ E.

III. 1st true bearing Beachy Head, N. 3° 38′ W., or N. ⅜ W.; 2nd true bearing N. 75° 8′ E., or E. by N. ½ N. Lat. 50° 41′ N., long. 0° 7½′ W., dist. 13½ miles.

IV. True course S. 88° 36′ W., or W. ⅛ S.; compass course S. 86° 36′ W., or W. ¼ S., dist. 17 miles. Deviation 20° E.

V. Standard Port for Reference—Portsmouth; constant for time + $0^h\ 4^m$; constant for height + 2 ft. 4 in.; time of high water, Selsea Bill, $11^h\ 58^m$ A.M.; height at high water, 15 ft. 5 in.; time from high water $2^h\ 58^m$; height above half tide 7 ft. 2 in.; $2^h\ 58^m$ and 7 ft. 2 in. = correction + 0 ft. 1½ in.; half spring range 8 ft. 3 in. *Correction* for sounding *subt.* 8 ft. 4½ in.

13. **Star.**—Star's decl. 5° 30′ 35″ N., true alt. 52° 45′ 55″, *latitude* 31° 43′ 30″ S., *Norie.* True alt. 52° 45′ 52″, *latitude* 31° 43′ 33″ S., *Raper.*

The Curve.—Correct magnetic bearing S. 2° E.

Deviations.—4° W.; 6° W.; 12° W.; 18° W.; 3° E.; 22° E.; 14° E.; 1° E.

Compass courses.—East; S. 50° E.; S. 40° W.; N. 4° W.

Magnetic courses.—S. 33° E.; N. 88½° W.; S. 30° W.; S.E. by E.

Bearings, magnetic.—N. 86½° W.; N. 2° W.

EXAMINATION PAPER—No. XIII, *Pages* 447-449.

1. 6·110455 = 1289598; 1·302556 = 20·0704.

2. 2·806180 = 640; 0·060635 = 1·14983.

3. **True Courses.**—S. 14° W., 23′ dep. course; S. 23° W., 51′; N. 87° W., 45′; S. 44° E., 22′; N. 78° W., 18′; N. 14° W., 44′; S. 3° E., 12′; West 52′ current course. *Diff. lat.* 48′·2 S.; *dep.* 134′·7 W.; *course* S. 70° W., *dist.* 143′. *Lat. in* 61° 30′ N.; *diff. long.* 286′ W. *Longitude in* 78° 31′ E.

4. Green. date Aug. $10^d\ 17^h\ 51^m\ 12^s$; red. decl. 15° 22′ 49″ N.; true alt. 42° 50′ 17″. *Latitude* 31° 46′ 54″ S.

By *Raper:* True alt. 42° 50′ 6″. *Latitude* 31° 47′ 5″ S.

5. Log. of diff. long. 2·663420 = *diff. long.* 460′·7.

6. Diff. lat. 2960′ N.; mer. diff. lat. 3413′; diff. long. 1333′ W.; log. tang. 9·591694; *course* N. 21° 20′ W.; log. dist. 3·502121; *distance* 3178′ (nearly).

7. Standard,	Brest	constant	+ $5^h\ 4^m$;	$0^h 18^m$ A.M., and	$0^h 42^m$ P.M.
,,	Portsmouth	,,	— 4 40;	10 57 A.M., and	11 22 P.M.
,,	Holyhead	,,	— 2 31;	11 42 A.M., and no	P.M.
,,	Weston-super-mare	,,	— 1 41;	8 48 A.M., and	9 10 P.M.

8. Green. date October $28^d\ 4^h\ 14^m\ 48^s$; red. decl. 13° 10′ 21″ S.; sine 9·546652; true amp. E. 20° 36′ 55″ S. *Error of compass* 31° 16′ 55″ E. *Deviation* 7° 26′ 55″ E.

9. Interval 15^d, rate $11^s·2$ *gaining*; interval $16^d\ 21\frac{1}{2}^h$, acc. rate $3^m\ 9^s$; Green. date April $17^d\ 21^h\ 21^m\ 54^s$; red. decl. 10° 46′ 24″ N.; true alt. 38° 22′ 36″; red. eq. T. *subt.* $0^m\ 38^s$; log. 9·067074; hour-angle $2^h\ 39^m\ 48^s$. *Longitude* 0° 35′ 15″ W.

Raper: True alt. 38° 22′ 25″; hour-angle $2^h\ 39^m\ 50^s$. *Longitude* 0° 35′ 45″ W.

10. Green. date Aug. $31^d\ 19^h\ 12^m\ 18^s$; red. decl. 8° 23′ 9″ N.; true alt. 44° 44′ 40″; sum of logs. 19·429728; true azimuth S. 62° 28′ 54″ W. *Error* 2° 12′ 21″ W.; *deviation* 3° 27′ 21″ W.

Raper: True alt. 44° 44′ 36″; true azimuth S. 62° 29′ W. *Error* 2° 12′ 15″ W. *Variation* 3° 27′ 15″ W.

Time azimuth: Red. eq. T. $0^m\ 0^s$ from M.T.; app. time at ship $2^h\ 38^m\ 12^s$; *true azimuth* N. 117° 36′ W.; *error* 2° 17′ W.; *deviation* 3° 32′ W.

11. Time from noon $25^m\ 52^s$; Green. date July $28^d\ 2^h\ 10^m\ 8^s$; red. decl. 18° 59′ 39″ N.; true alt. 69° 22′ 19″; nat. no. 4681; mer. zen. dist. 19° 51′ 10″ N. *Latitude* 38° 50′ 49″ N.

METHOD II. + 47′ 16″; true alt. 69° 22′ 19″. *Latitude* 38° 50′ 4″ N., *Norie.* *Raper:* True alt. 69° 22′ 15″. *Latitude* 38° 50′ 8″.

Towson: Exceeds limits of Table.

12. 1st red. decl. 7° 49′ 32″ S.; 1st red. eq. T. + 12^{m} 40^{s}·8; 1st true alt. 27° 41′ 12″; lat. 47° 10′ gives hour-angle 2^{h} 12^{m} 15^{s}; long. 165° 56½′ W. (A). Lat. 47° 40′ gives hour-angle 2^{h} 8^{m} 20^{s}; long. 164° 57¾′ W. (A′). 2nd red. decl. 7° 46′ 21″; 2nd red. eq. T + 12^{m} 39^{s}; true alt. 32° 50′ 32″; lat. 47° 10′ gives long. 165° 28′ W. (B). Lat. 47° 40′ gives long. 167° 30¾′ W. (B′). The line of bearing at the first observation trends N.E. ¾ E. Sun's true azimuth S. 37° E. Ship at second observation in lat. 47° 15½′ N., long. 165° 50½′ W 2nd line of bearing, B B′, W. by N. ¾ N. Azimuth S. 20° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from Cape Alprech to Beachy Head, W. ½ N., or N. 87° 11′ W.; dev. 17° 30′ W.; compass course N. 52° 41′ W., or N.W. ¾ W., distance 51 miles.

II. True bearing Varne Light, N. 47° 4′ E., or N.E. ½ E.; true bearing of Dungeness, N. 7° 41′ E., or N. ¾ E. Lat. 50° 44′ N., long. 0° 56′ E.

III. 1st true bearing Dungeness, N. 28° 52′ W., N.N.W. ½ W.; 2nd true bearing N. 38° 38′ E., or N.E. ½ N. Lat. 50° 43′ N., long. 0° 44′ E., distance 15 miles.

IV. True course N. 74° 32′ W., or W. by N. ⅜ N.; compass course N. 43° 9′ W., or N.W. ⅛ N., distance 66½ miles. Deviation 14° 23′ W.

V. Standard Port for Reference—Dover; constant for time + 0^{h} 8^{m}; constant for height + 0 ft. 8 in.; time of high water Beachy Head 0^{h} 20^{m} P.M.; height at high water 19 ft. 9 in.; time from high water 0^{h} 24^{m}; height above half tide 9 ft. 9 in.; 0^{h} 24^{m} and 9 ft. 9 in. = correction + 9 ft. 6 in.; half spring range 10 ft. 0 in. Correction for soundings *subt.* 19 ft. 6 in.

13. **Star.**—Star's decl. 47° 30′ 21″ S.; true alt. 49° 54′ 3″. *Latitude* 7° 24′ 24″ S., *Norie.*
„ „ „ 49 53 54 „ 7 24 15 S., *Raper.*

The Curve.—Correct magnetic bearing East.

Deviations.—0°; 23° W.; 30° W.; 22° W.; 3° W.; 27° E.; 30° E.; 21° E.

Compass courses.—S. 21½° W.; N. 41° E.; North; S. 67° E.

Magnetic courses.—N. 70° W.; N. 20½° W.; S. 7½° W.; S. 32° E.

Bearings, magnetic.—N. 65½° E.; S. 48½° W.

EXAMINATION PAPER—No. XIV, *Pages* 449-451.

1. 2·478098 = nat. no. 300·675. 4·214537 = 16388·38.

2. 4·906874 = nat. no. 807002. 6·688798 = ·0004884.

3. **True Courses.**—S. 1° E., 15′ dep. course; N. 75° E., 42′; N. 62° E., 32′; N. 59° W., 37′; S. 11° E., 37′; N. 51° E., 38′; N. 55° E., 28′; N. 10° E., 17′·5 current course. *Diff. lat.* 50′·9 N., *dep.* 100′·0 E.; *course* N. 63° E.; *dist.* 112′. *Lat. in* 31° 7′ N.; *mid. lat.* 30° 41′; *diff. long.* 116′·3; *long. in* 181° 48′ E. or 178° 12′ W.

4. Green. date March 20^{d} 11^{h} 36^{m}; red. decl. 0° 1′ 24″ N.; true alt. 90° 7′ 18″. *Lat.* 0° 8′ 42″ N.

Raper: True alt. 90° 7′ 10″. *Latitude* 0° 8′ 34″ N.

5. Log. of diff. long. 2·718690 = *Diff. long.* 523′·2.

6. Diff. lat. 189′ S.; mer. diff. lat. 189′; diff. long. 147° 35′ E. = 8855′ E.; tang. course 11·670727; *course* S. 88° 46′ 38″ E.; *log. distance* 3·947280; *distance* 8857′.

7. Standard,	Devonport	+ 0^{h} 38^{m};	11^{h}53^{m} A.M., and no P.M.
„	Portsmouth	— 1 41 ;	3 26 A.M., and 3^{h}55^{m} P.M.
„	Brest	+ 2 18 ;	12 0 A.M., and no P.M.
„	Weston-super-mare	— 1 12 ;	11 10 A.M., and 11 41 P.M.
„	Weston-super-mare	— 1 41 ;	10 41 A.M., and 11 12 P.M.
„	Devonport	— 0 29 ;	10 46 A.M., and 11 17 P.M.

8. Green. date Dec. 5^{d} 10^{h} 59^{m} 52^{s}; red. decl. 22° 26′ 15″ S.; sine amp. 9·995515; true amp. E. 81° 46′ 48″ S. *Error* 16° 39′ 27″ W.; *deviation* 8° 10′ 33″ E.

9. Interval $62^{d}\ 10\frac{1}{2}^{h}$, accumulated rate $+\ 3^{m}\ 38^{s}{\cdot}6$, Green. date Aug. $31^{d}\ 10^{h}\ 29^{m}\ 19^{s}$, red. decl. 8° 31′ 3″ N., eq. time $+\ 0^{m}\ 6^{s}{\cdot}8$, true alt. 40° 0′ 24″, hour-angle $2^{h}\ 26^{m}\ 30^{s}$, M.T. ship Aug. $31^{d}\ 21^{h}\ 33^{m}\ 37^{s}$. *Longitude* 166° 4′ 30″ E.

Raper: True alt. 40° 0′ 20″; hour-angle $2^{h}\ 26^{m}\ 30^{s}$. *Longitude* 166° 4′ 30″ E.

10. Green. date March $19^{d}\ 23^{h}\ 44^{m}\ 40^{s}$; red. decl. 0° 10′ 26″ S.; true alt. 35° 14′ 22″; sum of logs. 19·216385; true azimuth S. 47° 52′ 6″ E. *Error* 45° 3′ 21″ W.; *deviation* 17° 53′ 21″ W.

Raper: True alt. 35° 14′ 19″; true azimuth S. 47° 52′ 15″ E. *Error* 45° 3′ 30″ W, *deviation* 17° 53′ 30″ W.

Time azimuth: Red. eq. T. $7^{m}\ 38^{s}$ *subt.* from M.T.; app. time ship $9^{h}\ 30^{m}\ 28^{s}$; *true azimuth* N. 131° 38′ E.; *error* 45° 33′ W.; *deviation* 18° 23′ W.

11. Red. eq. T. $7^{m}\ 26^{s}{\cdot}0$ *add* to M.T.; time from noon $9^{m}\ 41^{s}$; red. decl. 0° 8′ 23″ N.; true alt. 61° 51′ 21″; nat. no. 787; mer. zen. dist. 28° 2′ 53″ S. *Latitude* 27° 54′ 30″ S.

Method II.—*Norie:* + 5′ 43″. True alt. 61° 51′ 21″; *latitude* 27° 54′ 33″ S. *Raper:* True alt. 61° 51′ 16″; *latitude* 27° 54′ 38″ S.

Towson: Aug. I 0; index 12. Aug. II + 5′ 57″. *Latitude* 27° 54′ 19″ S.

12. 1st red. decl. 0° 56′ 43″ S.; 1st red. eq. T. — $8^{m}\ 23^{s}{\cdot}5$; 1st true alt. 11° 0′ 50″; lat. 47° 10′ N. gives long. 179° 23½′ E. (A). Lat. 46° 40′ gives long. 179° 13′ E. (A′). 2nd red. decl. 1° 4′ 28″ S.; 2nd red. eq. T. — $8^{m}\ 30^{s}{\cdot}2$; 2nd true alt. 26° 58′ 43″; lat. 47° 10′ gives long. 179° 23½′ E. (B). Lat. 46° 40′ gives long. 179° 54½′ E. (B′). The line of bearing at first observation S. by W. ¼ W. Sun's true azimuth S. 76° E. The position of ship at second observation is lat. 46° 35′ N., long. 180°. 2nd line of bearing, B B′, S.E. by S. True Azimuth S. 55° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from A to Lizard Light N. 68° 54′ E., or E. by N. ⅞ N. Deviation 25° W. Compass course S. 65° 6′ E., or S.E. by E. ¾ E., distance 74½ miles.

II. True bearing of Longships N. 41° 11′ E., or N.E. ⅜ N.; true bearing of St. Agnes' light S. 77° 45′ W., or W. by S. ⅛ S.; latitude 49° 57′ N.; longitude 5° 55′ W.

III. 1st true bearing of Wolf Rock N. 1° 49′ E., or N. ⅛ E.; 2nd true bearing N. 88° 11′ W., or W. ⅛ N.; latitude 49° 56′ N.; longitude 5° 27′ W.; distance 13½ miles.

IV. True course N. 78° 45′ E., or E. by N.; deviation 25° W. Compass course S. 55° 15′ E., or S.E. ⅞ E.; distance 78 miles.

V. Standard Port for Reference—Devonport; constant for time — $1^{h}\ 16^{m}$; constant for height + 0 ft. 6 in; time of high water, St. Mary's, $10^{h}\ 59^{m}$ A.M.; height of tide, St. Mary's, 13 ft. 0 in.; time from high water $4^{h}\ 51^{m}$; height above half tide 5 ft. 0 in.; half spring range 8 ft. 0 in.; $4^{h}\ 51^{m}$ and 5 ft. 0 in. = correction — 4 ft. 1 in. Correction for sounding *subt.* 3 ft. 11 in.

13. **Star.**—Decl. (α Cygni) Deneb 44° 53′ 0″ N.; true alt. 56° 13′ 50″. *Lat.* 11° 6′ 50″ N. *Raper:* True alt. 56° 13′ 41″. *Latitude* 11° 6′ 41″ N.

The Curve.—Correct magnetic bearing S. 82° W.

Deviations.—21° W.; 10° W.; 3° W.; 4° E.; 20° E.; 23° E.; 5° E.; 17° W.

Compass courses.—N. 64½° E.; S. 10½° W.; S. 68½° E.

Magnetic courses.—N. 87½° W.; N. 54° W.; N. 22° E.

Bearings, magnetic.—N. 17° W.; S. 84½° E.

EXAMINATION PAPER—No. XV, *Pages* 451-453.

1. 5·903094 = 800007·4; 7·718169 = 52260000.

2. 8·850814 = ·0709274; 4·301030 = 20000.

3. **True Courses.**—S. 40° E., 21′ dep. course; S. 65° E., 14′; N. 54° W., 9′; N. 23° E., 18′; S. 10° W., 22′; S. 60° W., 29′; N. 16° E., 20′·6; N. 79° E., 14′ current course. Diff. lat. 13′·8 S., dep. 16′·4 E.; course S. 49½° E., dist. 21′. *Lat. in* 34° 42′ S., *diff. long.* 20′ E., *Long. in* 18° 48′ E.

4. Green. date February $10^d\ 21^h\ 51^m\ 0^s$; red. decl. 14° 3′ 1″ S.; true alt. 30° 32′ 9″. *Lat.* 45° 24′ 50″ N.

Raper: True alt. 30° 32′ 7″. *Latitude* 45° 24′ 52″ N.

5. Log. of diff. long. 2·997140 = *Diff. long.* 993·4.

6. Diff. lat. 4202′ N.; mer. diff. lat. 4555′; diff. long. 4847′ E.; tang. course 10·026985; *course* N. 46° 46′ 44″ E.; *log. of distance* 3·787882; *distance* 6136.

7. Standard, Holyhead constant — $2^h 11^m$; $10^h\ 3^m$ A.M., and $10^h 22^m$ P.M.
„ Greenock „ — 0 58 ; 1 0 A.M., and 1 17 P.M.
„ Kingstown „ — 3 12 ; 10 5 A.M., and 10 23 P.M.
„ Belfast „ — 4 18 ; 8 34 A.M., and 8 53 P.M.
„ Greenock „ — 0 23 ; 1 35 A.M., and 1 52 P.M.

8. Green. date March $30^d\ 7^h\ 41^m\ 8^s$; red. decl. 3° 52′ 53″ N.; sine 8·833347, true amp. E. 3° 54′ 24″ N. *Error* 7° 45′ 24″ W.; *deviation* 13° 45′ 24″ W.

9. Interval $32^d\ 21^h$; accumulated rate — $2^m\ 41^s$; Green. date May $26^d\ 21^h\ 10^m\ 6^s$; red. decl. 21° 16′ 19″ N.; red. eq. T. $3^m\ 8^s$ *subt.*; true alt. 43° 20′ 9″; hour-angle $2^h\ 53^m\ 8^s$. *Longitude* 1° 35′ 30″ W.

Raper: True alt. 43° 20′ 3″; hour-angle $2^h\ 53^m\ 9^s$. *Longitude* 1° 35′ 45″ W.

10. Green. date July $10^d\ 0^h\ 25^m\ 20^s$; red. decl. 22° 15′ 26″ N.; true alt. 44° 59′ 38″; sum of logs. 19·233002; true azimuth S. 48° 54′ 10″ E. *Error* 54° 28′ 40″ W.; *deviation* 3° 28′ 40″ W.

Raper: True alt. 44° 59′ 33″; true azimuth S. 48° 51′ 30″ E. *Error* 54° 29′ W.; *deviation* 3° 29′ W.

Time Azimuth: Red. eq. T. $5^m\ 2^s$ *subt.* from M.T.; app. time ship $9^h\ 39^m\ 0^s$; *true azimuth* N. 131° 4′ E.; *error of compass* 54° 34′ W.; *deviation* 3° 34′ W.

11. Red. eq. T. $0^m\ 5^s$ *add* to M.T.; time from noon $14^m\ 22^s$; red. decl. 23° 16′ 14″ S.; true alt. 55° 29′ 4″; nat. no. 965; mer. zen. dist. 34° 25′ 4″ N. *Latitude* 57° 41′ 18″ N.

METHOD II. + 5′ 51″. True alt. *(Norie)* 55° 29′ 4″; *latitude* 57° 41′ 19″ N. *Raper:* True alt. 55° 28′ 59″; *latitude* 57° 41′ 24″ N.

Towson: Aug. I + 2′ 28″; index 22. Aug. II + 8′ 28″. *Latitude* 57° 41′ 10″ N.

12. 1st red. decl. 20° 47′ 51″ S.; 1st red. eq. T. + $10^m\ 14^s$; 1st true alt. 13° 18′ 21″; lat. 46° 0′ gives long. 54° 23½′ E. (A). Lat. 46° 30′ gives long. 55° 16¾′ E. (A′). 2nd red. decl. 20° 44′ 49″ S.; 2nd red. eq. T. + $10^m\ 18^s{\cdot}6$; 2nd true alt. 8° 53′ 23″; lat. 46° 0′ gives long. 54° 45¾′ E. (B). Lat. 46° 30′ gives long. 54° 5½′ E. (B′). The line of bearing at the first observation trends N.E. ½ E. Sun's true bearing S. 39½° E. 2nd line of bearing, B B′, N.W. ¼ N.; azimuth S. 48° W. Ship at the second observation in lat. 46° 29′ N., long. 54° 7′ E.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from A to Lundy Island N. 47° 49′ E., or N.E. ¼ E. Deviation 22° 15′ W. Compass course S. 88° 56′ E., or East, distance 45½ miles.

II. True bearing of Longships light S. 71° 23′ E., or E. by S. ⅝ S.; true bearing of Seven Stones S. 29° 53′ W., or S.S.W. ⅝ W. Latitude 50° 7½′ N.; longitude 6° W.

III. 1st true bearing N. 86° 7′ E., or E. ⅜ N.; 2nd true bearing S. 48° 53′ E., or S.E. ⅜ E. Latitude 50° 41′ N.; Longitude 5° 16′ W.; distance 12½ miles.

IV. True course N. 57° 39′ E. or N.E. by E. ⅛ E. Deviation 24° W. Compass course S. 77° 21′ E., or E. by S. ⅛ S., distance 49½ miles.

V. Standard Port for Reference—Weston-super-Mare; constant for time — $2^h\ 10^m$; constant for height — 16 ft. 0 in.; time of high water at St. Ives $11^h\ 24^m$ P.M.; height of tide, St. Ives, 14 ft. 8 in.; time from high water $1^h\ 54^m$; height above half tide 4 ft. 2 in.; half spring range 10 ft. 6 in.; $1^h\ 54^m$ and 4 ft. 2 in. = correction + 2 ft. 3 in. Correction for sounding *subt.* 12 ft. 9 in.

13. **Star.**—Decl. α Pavonis 57° 5' 30" S.; true alt. 32° 48' 59". *Latitude* 0° 5' 31" N.

Raper: True alt. 32° 48' 53". *Latitude* 0° 5' 37" N.

The Curve.—Correct magnetic bearing S. 17° E.

Deviations.—27° E.; 39° E.; 22° E.; 5° W.; 28° W.; 30° W.; 21° W.; 5° W.

Compass courses.—N. 28° W.; N. 58° W.; S. 79½° W.; S. 89° W.

Magnetic courses.—S. 80° E.; S. 42° E.; N. 66° W.; S. 87° E.

Bearings, magnetic.—N. 28° E.; S. 63° E.

EXAMINATION PAPER—No. XVI, *Pages* 453-455.

1. 4·734724 = 54290·5; 9·823096 = ·66542.

2. 3·306211 = 2024; 1·671358 = 46·92.

3. True Courses.—N. 56° W., 13' dep. course; S. 70° W., 34'; S. 69° W., 36'·2; S. 59° W., 38'·6; S. 3° W., 34'·1; S. 10° W., 17'·2; N. 77° W., 33'·5; S. 10° W., 21' current course. *Diff. lat.* 101'·4 S.; *dep.* 150'·6 W.; *course* S. 56° W.; *dist.* 181½'. *Lat. in* 60° 57' S.; *diff. long.* 302'. *Longitude in* 184° 44' W. or 175° 16' E.

4. Green. date May $16^d\ 3^h\ 1^m\ 44^s$; red. decl. 19° 7' 7" N.; true alt. 86° 50' 42". *Latitude* 15° 57' 49" N.

Raper: True alt. 86° 50' 35". *Latitude* 15° 57' 42" N.

5. Log. of diff. long. 2·497139 = *Diff. long.* 314'·2.

6. Diff. lat. 604' S.; mer. diff. lat. 606'; diff. long. 6324' W.; tangent 11·018519; *course* S. 84° 31' 35" W.; *log. dist.* 3·801547; *distance* 6332'.

7. Standard, Brest, constant — $0^h 27^m$; no A.M., and $0^h 10^m$ P.M.
„ Brest, „ + 0 27; $0^h 26^m$ A.M., and 1 4 P.M.
„ Dover, „ + 4 33; 11 44 A.M., and no P.M.
„ Holyhead, „ — 1 41; 4 58 A.M., and 5 33 P.M.
„ Liverpool, „ + 0 47; 8 26 A.M., and 9 4 P.M.
„ Liverpool, „ — 0 19; 7 20 A.M., and 7 58 P.M.

8. Green. date June $24^d\ 11^h\ 41^m$; red. decl. 23° 25' N.; sine amp. 9·998835; true amp. W. 85° 48' 20" N. *Error* 12° 37' 55" W.; *deviation* 20° 52' 5" E.

9. Interval $42^d\ 23^h$, accumulated rate + $5^m\ 43^s·7$; Green. date June $14^d\ 23^h\ 6^m\ 21^s$; red. decl. 23° 18' 53" N.; red. eq. T. + $0^m\ 6^s·5$; true alt. 20° 48' 38"; hour-angle $3^h\ 7^m\ 30^s$; M.T. ship June $14^d\ 20^h\ 52^m\ 36^s$. *Longitude* 33° 26' 0" W.

Raper: True alt. 20 48' 25"; hour-angle $3^h\ 7^m\ 32^s$. *Longitude* 33° 26½' W.

10. Green. date September $23^d\ 10^h\ 9^m\ 47^s$; red. decl. 0° 12' 55" S.; true alt. 30° 28' 43": sum of logs. 19·195303: true azimuth N. 46° 39' 6" W. *Error* 60° 42' 51" W.: *deviation* 31° 52' 51" W.

Raper: True alt. 30° 28' 36": true azimuth N. 46° 39' 24" W. *Deviation* 31° 53' 9" W.

Time azimuth: Red. eq. T. $7^m\ 44^s·9$ + to M.T.: app. time ship $2^h\ 35^m\ 14^s$ P.M.: *true azimuth* S. 133° 24' W.: *error of compass* 60° 46' W.: *deviation* 31° 50' W.

11. Red. eq. T. $7^m\ 26^s·4$ *add* to M.T.; time from noon $19^m\ 16^s$; red. decl. 0° 7' 50" N.; true alt. 38° 58' 36"; nat. no. 2225; mer. zen. dist. 50° 51' 33" N. *Latitude* 50° 59' 23" N.

METHOD II.—*Reduction* + 9' 52". *Latitude* 50° 59' 22" N. (*Norie*). (*Raper*) true alt. 38° 53' 34"; *latitude* 50° 59' 24" N.

Towson: Aug. I. + 2", index 46. Aug. II, + 9' 50". *Latitude* 50° 59' 26" N.

12. 1st red. decl. 13° 11' 10" N.; 1st red. eq. T. + $3^m\ 44^s$; 1st true alt. 17° 40' 42"; lat. 49° 25' gives hour-angle $5^h\ 12^m\ 28^s$; long. 19° 53' W. (A). Lat. 49° 55' gives hour-angle $5^h\ 12^h\ 27^m$; long. 19° 52¾' W. (A') 2nd red. decl. 13° 9' 0" N.; 2nd red. eq. T. + $3^m\ 43^s$; 2nd true alt. 41° 56' 2"; lat. 49° 25' gives hour-angle $2^h\ 34^m\ 10^s$; long. 20° 43½' W. (B). Lat. 49° 55' gives hour-angle $2^h\ 31^m\ 56^s$; long. 20° 10' W. (B'). The line of bearing at the first observation trends North. Sun's true bearing East. The position of the ship at the second observation is lat. 49° 45' N., long. 20° 20½' W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. Magnetic course from A to the Bill of Portland, N. 83° 41′ E., or E. ½ N.; Dev. 24° 30′ W. Compass course S. 71° 49′ E., or E. by S. ⅝ S., distance 84 miles.

II. Magnetic bearing, Eddystone, N. 49° 49′ W., or N.W. ½ W.; magnetic bearing, Start Point, N. 55° 39′ E., or N.E. by E. Latitude 50° 4′ N.; longitude 3° 49′ W.

III. 1st magnetic bearing, Start, N. 7° 37′ W., or N. ⅝ W.; 2nd magnetic bearing Start, N. 72° 19′ W., or W. by N. ⅝ N. Latitude 50° 13½′ N.; longitude 3° 24′ W.; distance 9 miles.

IV. Magnetic course, E.N.E. or N. 66° 49′ E., Deviation 22° W. Compass course N. 88° 49′ E., or E. ⅛ N., distance 32 miles.

V. Standard Port for Reference—Devonport; constant for time + 0^h 38^m; constant for height — 3 ft. 0 in.; time of high water at Exmouth 0^h 28^m P.M.; height of tide, Exmouth, 8 ft. 11 in.; time from high water 2^h 48^m; half spring range 6 ft. 1½ in.; height above half tide 2 ft. 9½ in.; 2^h 48^m and 2 ft. 9½ in. = correction + 0 ft. 3½ in. Correction for sounding *subt*. 6 ft. 5 in.

13. **Star.**—Spica's decl. 10° 34′ 22″ S.; true alt. 52° 9′ 5″. *Latitude* 48° 25′ 17″ S.

Raper: True alt. 52° 9′ 0″. *Latitude* 48° 25′ 22″ S.

The Curve.—Correct magnetic bearing S. 11° W.

Deviations.—24° W.; 2° W.; 5° E.; 8° E.; 21° E.; 22° E.; 3° W.; 26° W.

Compass courses.—N. 85° E.; S. 46° W.; S. 42½° E.

Magnetic courses.—N. 81° W.; N. 23° W.; N. 70° E.

Bearings, magnetic.—(Deviation for ship's head W.S.W. = 10½° E.) S. 89½° W., S. 10½° W.

EXAMINATION PAPER—No. XVII, *Pages* 455-457.

1. 7·651355 = 44807938·1. 1·351334 = 22·4561.

2. 5·614476 = 411600·94. 9·030734 = ·107333.

3. **True Courses.**—S. 78° E., 20′, dep. course; East, 43′; N. 86° E., 44′; N. 81° E., 48′; S. 89° E., 43′; N. 87° E., 42′; N. 58° E., 44′; N. 49° E., 78′ current course. *Diff. lat.* 82′·3 N.; *dep.* 335′ E.; *course* N. 76° E.; *dist.* 343′·4. *Lat. in* 38° 59′ N.; *diff. long.* 427′ E. *Long. in* 6° 26′ E.

4. Green. date Nov. 20^d 19^h 18^m 40^s; red. decl. 19° 52′ 41″ S.; true alt. 80° 28′ 59″. *Latitude* 29° 23′ 42″ S.

Raper: True alt. 80° 28′ 56″ N. *Latitude* 29° 23′ 45″ S.

5. Log. of diff. long. 2·728753 = *diff. long.* 535′·5.

6. Diff. lat. 2061′ S.; mer. diff. lat. 2101′; diff. long. 10096′ E.; log. tang. 10·681724; *course* S. 78° 14′ 40″ E.; *log. distance* 4·005008; *distance* 10116′.

7.	Standard,	Harwich,	constant	— $0^h 51^m$;	no A.M., and	$0^h 19^m$ P.M.
	„	Greenock	„	— 0 56;	no A.M., and	0 16 P.M.
	„	Holyhead	„	+ 0 57;	no A.M., and	0 9 P.M.
	„	Kingstown	„	— 0 2;	no A.M., and	0 9 P.M.
	„	Dover	„	+ 1 13;	1^h 8^m A.M., and	1 32 P.M.

8. Green. date June 29^d 2^h 53^m 26^s; red. decl. 23° 14′ 24″ N.; true amp. E. 53° 58′ 46″ N. *Error of compass* 50° 4′ 59″ E.; *deviation* 29° 54′ 49″ E.

9. Interval 34^d 12^h; Green. date June 4^d 12^h 29^m 23^s; red. decl. 22° 29′ 36″ N.; true alt. 28° 18′ 52″; red. eq. T. *subt.* 1^m 54^s; hour-angle 3^h 52^m 19^s; M.T. ship June 4^d 20^h 5^m 46^s. *Longitude* 114° 5′ 45″ E.

Raper: True alt. 28° 18′ 42″; hour-angle 3^h 52^m 19^s. *Longitude* 114° 5′ 45″ E.

10. Green. date Sept. 28^d 14^h 14^m 57^s; red. decl. 2° 13′ 55″ S.; true alt. 29° 30′ 8″; sum of logs. 18·907403; true azimuth S. 33° 1′ 42″ W. *Error* 38° 39′ 12″ E.; *deviation* 23° 24′ 12″ E.

Raper: True alt. 29° 29′ 54″; true azimuth S. 33° 2′ 28″ W. *Deviation* 23° 24′ 58″ E.

Time azimuth: Red. eq. T. 9^m 30^s·2 *add* to M.T.; app. time at ship 1^h 51^m 5^s P.M.; *true azimuth* N. 147° 32′ W.; *error* 38° 6′ E.; *deviation* 22° 51′ E.

11. Time from noon 18^{m} 11^{s}; Green. date May 30^{d} 0^{h} 21^{m} 6^{s}; red. decl. 21° 46′ 9″ N.; true alt. 40° 3′ 52″; nat. no. 926; mer. zen. dist. 49° 51′ 59″ S. *Latitude* 71° 38′ 8″ N.

METHOD II. Red. + 4′ 10″. *Latitude* 71° 38′ 7″ N., (*Norie*).

Raper: True alt. 40° 3′ 45″. *Latitude* 71° 38′ 14″ N.

Towson: Aug. I + 3′ 45″; index 35½. Aug. II + 7′ 50″. *Latitude* 71° 38′ 12″ N.

12. 1st red. decl. 23° 4′ 9″ N.; 1st red. eq. T. + 3^{m} 40^{s}; 1st true alt. 31° 19′ 36″; lat. 48° 0′ gives hour-angle 4^{h} 32^{m} 46^{s}; long. 7° 47¼′ W. (A). Lat. 48° 20′ N. gives hour-angle 4^{h} 32^{m} 46^{s}; long. 7° 47¼′ W. (A′). 2nd red. decl. 23° 3′ 44″ N.; 2nd red. eq. T. + 3^{m} 41^{s}; 2nd true alt. 53° 1′ 18″. Lat. 48° 0′ gives hour-angle 2^{h} 17^{m} 45^{s}; long. 8° 8¼′ W. (B). Lat. 48° 20′ gives hour-angle 2^{h} 16^{m} 35^{s}; long. 7° 50¾′ W. (B′). The line of bearing at the first observation trends North. Sun's azimuth East. 2nd line of bearing, B B′, N.N.E. ¾ E. Azimuth S. 59° E. The ship's position at second observation is lat. 48° 14′ N., long. 7° 56′ W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. Magnetic course from A to Hanois, N. 84° 11′ E., or E. ½ N. Deviation 24° 30′ W. Compass course S. 71° 19′ E., or E. by S. ⅝ S., distance 71 miles.

II. Magnetic bearing of Isle de Bas S. 12° 4′ W., or S. by W. ⅛ W.; magnetic bearing, Triagoz, S. 41° 23′ E., or S.E. ⅜ S. Latitude 49° 3′ N.; longitude 4° 4′ W.

III. 1st magnetic bearing, Isle de Bas, S. 61° 4′ E., or S.E. by E. ½ E.; 2nd magnetic bearing S. 4° 49′ E., or S. ½ E. Latitude 48° 54½′ N.; longitude 4° 8′ W.; distance 10 miles.

IV. Magnetic course S. 78° 45′ E., or E. by S. Deviation 25° W. Compass course S. 53° 45′ E., or S.E. ¾ E., distance 40½ miles.

V. Standard Port for Reference—Brest; constant for time + 2^{h} 50^{m}; constant for height + 7 ft. 0 in.; time of high water, Port St. Peter, 3^{h} 15^{m} P.M.; height of tide, St. Peter, 22 ft. 8 in.; time from high water 4^{h} 33^{m}; half spring range 13 ft. 9 in.; height above half tide 9 ft. 8 in.; 4^{h} 33^{m} and 9 ft. 8 in. = correction — 7 ft. 0 in. Correction for sounding *subt.* 6 ft. 0 in.

13. **Star.**—Star's decl. 16° 34′ 0″ S.; true alt. 37° 44′ 55″. *Latitude* 35° 41′ 5″ N. (*Norie*).

Raper: True alt. 37° 44′ 49″. *Latitude* 35° 41′ 11″ N.

The Curve.—Correct magnetic bearing N. 12° E.

Deviations.—12° E.; 0°; 17° W.; 24° W.; 12° W.; 7° E.; 17° E.; 17° E.

Compass courses.—N. 85° W.; S. 57° W.; S. 34° E.; S. 8° E.

Magnetic courses.—N. 86° E.; S.E. by S.; N. 38½° W.; N. 79° W.

Bearings, magnetic.—(Deviation for ship's head E. by S. ½ S. = 20½′ W.); N. 82½° W.; S. 37½° E.

EXAMINATION PAPER—No. XVIII, *Pages* 457-459.

1. Log. of product 9·429429 = product 2688000000; Log. $\bar{6}$·233506, product ·000001712.

2. Log. of quotient 4·986680 = quotient 96979·6; Log. $\bar{2}$·439591 product ·027523.

True Courses.—N. 69° W., 25′ d p. course; N. 58° W., 51′; S. 63° W., 42′; N. 51° E., 30′; N. 36° W., 46′; S. 27° W., 11′; S. 68° E., 16; S. 51° W., 32′ current course. *Diff. lat.* 37′·1 N.; *dep.* 122′·8 W.; *course* N. 73° W.; *dist.* 128′. *Latitude in* 35° 50′ S.; *mid. lat.* 36° 8′; *diff. long.* 152′ W. *Longitude in* 71° 9′ W.

4. Green. date, 1887, Dec. 31^{d} 12^{h} 48^{m} 24^{s}; red. decl. 23° 4′ 7″ N.; true alt. 83° 52′ 24″. *Latitude* 29° 11′ 43″ N.

Raper: True alt. 83° 52′ 20″. *Latitude* 29° 11′ 47″ S.

5. Log. diff. long. 2·284397; diff. long. 192′·5 W. *Long. in* 182° 29′·5 W., or 177° 30½′ E.

6. Diff. lat. 2747′ S.; mer. diff. lat. 2919′; diff. long. 6340′ W.; tang. course 10·336855; *course* S. 65° 16′ 41″ W.; *log. distance* 3·817459; *distance* 6568′.

7. Standard,	Portsmouth	constant	$-0^h 41^m$;	$11^h\ 1^m$ A.M., and $11^h 22^m$ P.M.
,,	Dover	,,	$+0\ 39$;	11 50 A.M., and no P.M.
,,	Harwich	,,	$-2\ \ 9$;	10 1 A.M., and 10 23 P.M.
,,	Greenock	,,	$-0\ 19$;	11 49 A.M., and no P.M.
,,	Kingstown	,,	$+1\ 19$;	0 9 A.M., and 0 29 P.M.

8. Green. date Nov. $3^d\ 17^h\ 28^m\ 30^s$; red. decl. 15° 17′ 13″ S.; true amp. E. 22° 35′ 38″ S. *Error* 28° 1′ 52″ W.; *deviation* 11° 31′ 52″ W.

9. Interval 14^d, rate $8^s{\cdot}5$ *gaining*, interval $124^d\ 20^h$, accumulated rate $-17^m\ 41^s$, Green. date August $31^d\ 19^h\ 54^m\ 30^s$, red. decl. 8° 22′ 31″ N., eq. T. $-0^m\ 1^s$, true alt. 15° 25′ 44″, sum of logs. 9·531507, hour-angle $4^h\ 45^m\ 22^s$. *Long.* 9° 58′ 15″ W.

Raper: True alt. 15° 25′ 31″; hour-angle $4^h\ 45^m\ 22^s$. *Longitude* 9° 58′ 15″ E.

10. Green. date, May $31^d\ 16^h\ 13^m$; red. decl. 22° 0′ 30″ N.; true alt. 39° 20′ 26″; sum of logs. 19·778953; true azimuth S. 101° 40′ 0″ E. *Error* 3° 13′ 45″ W.; *deviation* 4° 3′ 45″ W.

Raper: True alt. 39° 20′ 19″; true azimuth S. 101° 40′ 3″ E. *Deviation* 4° 3′ 48″ W.

Time azimuth: Red. eq. T. $2^m\ 31^s$ *add* to M.T.; app. time at ship $8^h\ 21^m\ 31^s$. *True azimuth* N. 78° 16′ E.; *error* 3° 18′ W.; *deviation* 4° 8′ W.

11. Green. date, April $12^d\ 14^h\ 1^m\ 5^s$; time from noon $10^m\ 15^s$; red. decl. 8° 52′ 54″ N.; true alt. 80° 43′ 11″; nat. no. 988; mer. zen. dist. 8° 55′ 21″ S. *Latitude* 0° 2′ 27″ S.

METHOD II. + 22′ 0″; *latitude* 0° 1′ 55″ S. (*Norie*). *Latitude* 0° 2′ 5″ S. (*Raper*).

Towson: The altitude exceeds the limits of the Table.

12. 1st red. decl. 4° 30′ 14″ N.; 1st red. eq. T. $+4^m\ 0^s$; 1st true alt. 35° 3′ 30″; lat. 51° 0′ gives hour-angle $2^h\ 20^m\ 20^s$; long. 9° 38½′ W. (A). Lat. 50° 30′ gives hour-angle $2^h\ 23^m\ 30^s$; long. 10° 25¾′ W. (A′). 2nd red. decl. 4° 35′ 19″ N.; 2nd red. eq. T. $+3^m\ 56^s$; 2nd true alt. 31° 31′ 9″; lat. 51° 0′ gives long. 11° 6¼′ W. (B). Lat. 50° 30′ gives long. 10° 30½′ W. (B′). The line of bearing at first observation trends S.W. Azimuth S. 45° E. 2nd line of bearing B B′, S.E. ¾ S. Azimuth S. 53½° W. Ship at time of second observation, lat. 50° 28½′ N., long. 10° 28′ W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from A to Ushant, S.W. ⅛ W., or S. 46° 24′ W.; magnetic course S. 67° 24′ W., or W.S.W. Dev. 28° E. Compass course S. 39° 24′ W., or S.W. ½ S., distance 70½ miles.

II. True bearing of Triagoz, S. 26° 45′ E., or S.S.E. ¾ E.; true bearing of Isle de Bas, S. 21° 4′ W., or S. by W. ¾ W. Latitude 49° 6′ N.; longitude 3° 49′ W.

III. 1st true bearing of Isle de Bas, S. 18° 15′ W., or S. by W. ⅝ W.; 2nd true bearing S. 46° 26′ E., or S E ⅛ E. Latitude 48° 52′ N.; longitude 4° 13′ W.; distance 10½ miles.

IV. True course S.S.W. ⅝ W., or S. 29° 32′ W.; magnetic course S.W. ½ W., or S. 50° 32′ W.; deviation 24° E. Compass course S.S.W. ⅜ W., or S. 26° 32′ W., distance 51½ miles.

V. Standard Port for Reference—Brest; constant for time $-0^h\ 15^m$; constant for height 0 ft. 0 in.; time of high water, Ushant, $6^h\ 24^m$ A.M.; height of high water, Ushant, 17 ft. 4 in.; time from high water $3^h\ 54^m$; half spring range 9 ft. 7½ in.; height above half tide 7 ft. 8½ in.; $3^h\ 54^m$ and 7 ft. 8½ in. = correction − 3 ft. 6 in. Correction for sounding *subt.* 6 ft. 1½ in.

13. Star.—α^2 Centauri's decl. 60° 22′ 3″ S.; true alt. 9° 52′ 32″. *Latitude* 19° 45′ 25″ N.

Raper: *Latitude* 19° 45′ 32″ N.

The Curve.—Correct magnetic bearing S. 8° E.

Deviations.—19° E.; 8° W.; 29° W.; 35° W.; 20° W.; 13° E.; 29° E.; 31° E.

Compass courses.—N. 2° E.; S. 60½° E.; S. 29° W.; N. 73° W.

Magnetic courses.—N. 11° W.; S. 62 E.; N. 50° E.; N. 34° E.

Bearings, magnetic.—N. 15½° E.; N. 52° W.

EXAMINATION PAPER—No. XIX, *Page* 459-461.

1. Log. 7·080996 = 12050250. Log. 5·938289 = 867540.

2. Log. 0·301030 = ·2. Log, 1·770558 = 58 96.

3.—True Courses.—N. 70° W.. 13′ dep. course; S. 20° W., 48′; S. 60° W., 37′·2; S. 54° W., 30′; N. 71° W., 43′·5; N. 66° W., 38′·4; N. 15° W., 37′·8; N. 36° W., 36′ current course. *Diff. lat.* 18′·5 N.; *dep.* 192′·3 W.; *course* N. 85° W.; *dist.* 193′. *Lat. in* 46° 1½′ S.; *diff. long.* 4° 38′ W. *Longitude in* 181° 22′ W., or 178° 38′ E.

4. Green. date Sept. 22^d 16^h 0^m 24^s; red. decl. 0° 4′ 55″ N.; true alt. 83° 52′ 20″. *Lat.* 6° 2′ 45″ S.

Raper: True alt. 83° 52′ 14″. *Latitude* 6° 2′ 51″ S.

5. Log. of diff. long. 2·159381 = *Diff. long.* 144′·3.

6. Diff. lat. 1199′ N.; mer. diff. lat. 1205′; diff. long. 3410′ W.: tang. course 10·451767; *course* N. 70° 32′ 17″ W.; *log. dist.* 3·556139; *dist.* 3599.

7. Standard, London constant, — $0^h 21^m$; $11^h 59^m$ A.M., and no P.M.
 „ Brest „ — 2 0 ; no A.M., and $0^h 10^m$ P.M.
 „ Leith „ — 2 21 ; 10 24 A.M., and 10 44 P.M.
 „ Greenock „ + 4 41 ; 2 23 A.M., and 2 45 P.M.
 „ Brest „ + 6 13 ; corr. for long. — 14^m; $7^h 49^m$ A.M., and $8^h 9^m$ P.M.

8. Green. date, August 1^d 3^h 53^m 56^s; red. decl. 18° 0′ 32″ N.; sine of true amplitude 9·779826; true amplitude E. 37° 2′ 10″ N. *Error* 54° 27′ 50″ E.; *deviation* 34° 42′ 50″ E.

9. Interval 70^d, daily rate (4^s·08 =) 4^s·1 *gaining*, interval 93^d 12^h, acc. rate — 6^m 23^s·3, red. decl. 23° 17′ 35″ N., red. eq. time + 0^m 0^s·68, true alt. 49° 11′ 9″, hour-angle 3^h 1^m 27^s·5, M.T. ship June 14^d 3^h 1^m 28^s. *Longitude* 134° 38′ 15″ W.

Raper: True alt. 49° 11′ 1″; hour-angle 3^h 1^m 28^s. *Long.* 134° 38′ W.

10. Green. date, 1887, Dec. 31^d 16^h 24^m 20^s; red. decl. 23° 3′ 23″ S.; true alt. 35° 1′ 13″; logs. 19·751220; true azimuth N. 97° 20′ 43″ W. *Error* 12° 58′ 13″ W.; *deviation* 32° 58′ 13″ W.

Raper: True alt. 35° 1′ 1″; true azimuth N. 97° 20′ 49″ W.; *deviation* 32° 58′ 19″ W.

Time azimuth: Red. eq. T. 3^m 30^s·4 *subt.* from M.T.; app. time at ship 4^h 6^m 30^s; *true azimuth* S. 82° 56′ W.; *error* 12° 41½′ W. *Deviation* 32° 41½′ W.

11. Time from noon 10^m 46^s; Green. date Dec. 30^d 18^h 40^m 19^s; red. decl. 23° 7′ 27″ S.; nat. no. 624, nat. cos. 257949; mer. zen. dist. 75° 3′ 6″ N. *Lat.* 51° 55′ 39″ N.

METHOD II. Red. + 2′ 13″. *Lat.* 51° 55′ 39″ N., *Norie.* *Lat.* 51° 55′ 49″ N., *Raper.*

Towson: Aug. I, + 1′ 23″; index 12. Aug. II, + 50″. *Latitude* 51° 55′ 39″ N.

12. 1st red. decl. 19° 14′ 6″ S.; 1st red. eq. T. + 12^m 17^s·6; true alt. 9° 41′ 48″; lat. 51° 15′ N. gives hour-angle 2^h 55^m 52^s; long. 0° 51′ W. (A); lat. 50° 45′ gives hour-angle 2^h 59^m 23^s; long. 1° 43¾′ W. (A′). 2nd red. decl. 19° 11′ 42″ S.; red. eq. T. + 12^m 20^s; true alt. 18° 37′ 49″; lat. 51° 15′; long. 3° 40¼′ W. (B). Lat. 50° 45′ gives long. 0° 36½′ W. (B′). The line of bearing when the first altitude was taken trends S.W. ¼ W. Sun's azimuth S. 42° E. Ship at second observation in lat. 50° 47′ N., long. 0° 48′ W. 2nd line of bearing, B B′, E. by S. ½ S. Azimuth S. 14° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from A to Saltees N.E. by E. ⅛ E., or N. 57° 39′ E. Magnetic course N. 79° 9′ E., or E. by N. Deviation 32° E. Compass course N. 47° 9′ E., or N.E. ¼ E., distance 80½ miles.

II. True bearing of Kinsale N. 72° W., or W. by N. ⅝ N. True bearing of Ballycottin N. 6° 30′ E., or N. ⅝ E. Latitude 51° 30½′ N.; longitude 8° 3′ W.

III. 1st true bearing Minehead N. 6° 30′ E., or N. ⅝ E.; 2nd true bearing N. 58° 24′ W., or N.W. by W. ¼ W.; latitude 51° 50′ N.; longitude 7° 11½′ W; distance 18 miles.

IV. True course E. by N. ¾ N., or N. 70° 19′ E. Magnetic course E. ¼ S., or S. 88° 11′ E. Deviation 32° E. Compass course N. 59° 49′ E., or N.E. by E. ¼ E., distance 62 miles.

V. Standard Port for Reference—Queenstown; constant for time — $0^h\ 18^m$; constant for height — 0 ft. 4 in.; time of high water at Kinsale $11^h\ 49^m$ A.M.; height of tide Kinsale 8 ft. 8 in.; time from high water $2^h\ 57^m$; half spring range 5 ft. 9 in.; height above half tide 2 ft. 11 in.; $2^h\ 57^m$ and 2 ft. 11 in. = correction + 0 ft. 1 in. Correction for sounding *subt.* 5 ft. 10 in.

13. **Star.**—Star's decl. 16° 34′ 4″ S., true alt. 60° 59′ 28″ *Latitude* 45° 34′ 36″ S.

Raper: True alt. 60° 59′ 18″. *Latitude* 45° 34′ 36″ S.

The Curve.—Correct magnetic bearing S. 8° E.

Deviations.—19° E.; 8° W.; 29° W.; 35° W.; 20° W.; 13° E.; 29° E.; 31° E.

Compass courses.—N. 2° E.; S. 60½° E.; S. 26° W.; N. 72½° W.

Magnetic courses.—N. 11° W.; S. 60° E.; N. 50° E.; N. 33° E.

Bearings, magnetic.—N. 16° E.; N. 50½° E.

EXAMINATION PAPER—No. XX, *Pages* 461-463.

1. Log. 3·026339 = product 1062·53; $\bar{2}$·138598 = ·013759.

2. Log. 3·954291 = quotient 9001·0; $\bar{5}$·301030 = ·00002; $\bar{6}$·301030 = ·000002; and 1·301030 = 20.

3. **True Courses.**—S. 26° W., 16′ dep. course; S. 87° E., 53′; S. 52° W., 15′; N. 70° E., 50′; N. 14° E., 9′; S. 30° E., 28′; N. 68° E., 47′; N. 82° E., 52′ current course. *Diff. lat.* 0, *dep.* 192′·4 E.; *course* East; *dist.* 192′·4. *Latitude in* 50° 25′ S.; *diff. long.* 301′·9 E.; *Longitude in* 184° 42′ E., or 175° 18′ W.

4. Green. date Sept. $22^d\ 20^h\ 9^m$; red. decl. 0° 0′ 52″ N.; true alt. 84° 21′ 18″. *Latitude* 5° 37′ 50″ S.

Raper: True alt. 84° 21′ 8″. *Latitude* 5° 38′ 0″ S.

5. *Log. D. long.* 2·344197 = *diff. long.* 220′·9 E., or 3° 41′ E. *Long in* 3° 1′ E.

6. Diff. lat. 2531′ S.; mer. diff. lat. 2701′; diff. long. 7433′ E.; tang. 10·439639; *course* S. 70° 1′ 48″ E.; *log. dist.* 3·869867; *distance* 7411′.

7. Standard, Brest, constant — $1^h 51^m$; no A.M.; $0^h\ 1^m$ P.M.
„ Leith, „ — 0 42 ; $11^h 44^m$ A.M.; no P.M.
„ Sunderland, „ — 1 14 ; no A.M.; 0 7 P.M.
„ Sligo, „ — 0 21 ; 2 45 A.M.; 3 7 P.M.

8. Green. date November $4^d\ 21^h\ 23^m$; red. decl. 15° 38′ 39″ S.; sine 9·459946; true amp. W. 16° 45′ 37″ S. *Error* 19° 48′ 8″ E.; *deviation* 18° 48′ 8″ E.

9. Green. date Aug. $5^d\ 8^h\ 8^m\ 44^s$, red. decl. 16° 54′ 56″ N., red. eq. time + $5^m\ 44^s{\cdot}9$, true alt. 35° 16′ 44″, hour-angle $3^h\ 54^m\ 16^s$. *Longitude* 179° 18′ 45″ W.

By *Raper:* True alt. 35° 16′ 32″; hour-angle $3^h\ 54^m\ 17^s$. *Long.* 179° 19′ W.

10. Green. date Aug. $13^d\ 2^h\ 20^m\ 40^s$; red. decl. 14° 40′ 28″ N.; true alt. 27° 23′ 29″; sum of logs. 19·254647; true azimuth N. 50° 10′ 10″ E. *Error* 25° 10′ 10″ E.; *deviation* 8° 50′ 10″ E.

By *Raper:* True alt. 27° 23′ 25″; *true azimuth* N. 50° 10′ 15″ E.; *deviation* 8° 50′ 15″ E.

Time azimuth: Red. eq. T. $4^m\ 40^s{\cdot}0$ *subt.* from M.T.; app. time at ship $9^h\ 0^m\ 40^s$; *true azimuth* S. 130° 13′ E.; *error* 24° 47′ E.; *deviation* 8° 27′ E.

11. Green. date June $11^d\ 19^h\ 43^m\ 30^s$, time from noon $32^m\ 18^s$, red. decl. 23° 8′ 41″ N., true alt. 50° 14′ 43″, nat. no. 8771, mer. zen. dist. 38° 57′ 45″ S. *Latitude* 15° 49′ 4″ S.

METHOD II. *Norie:* + 47° 56′. *Latitude* 15° 48′ 40″ S. *Raper: Latitude* 15° 48′ 50″ S.

Towson: Aug. I, + 12′ 22″, index 81. Aug. II, + 34′ 38″. *Latitude* 15° 49′ 36″ S.

12. 1st red. decl. 15° 2′ 46″ S.; 1st red. eq. T. — $16^m\ 19^s{\cdot}9$; 1st true alt. 19° 3′ 11″; lat. 51° 45′ gives hour-angle $1^h\ 50^m\ 0^s$; long. 11° 16¼′ W. (A). Lat. 51° 15′ gives hour-angle $1^h\ 55^m\ 50^s$; long. 12° 43¾′ W. (A′). 2nd red. decl. 15° 5′ 57″ S.; 2nd red. eq. T. — $16^m\ 19^s{\cdot}8$; 2nd true alt. 16° 41′ 27″; lat. 51° 45′ gives hour-angle $2^h\ 18^m\ 33^s$; long. 10° 30½′ W. (B). Lat. 51° 15′ gives hour-angle $2^h\ 23^m\ 3^s{\cdot}5$; long. 9° 23′ W. (B′). The line of bearing at the first observation trends S.W. by W. ½ W. Sun's azimuth S. 28° E. 2nd line of bearing, B B′, S.E. ¾ E. (easterly) Azimuth S. 35° W. Ship at second observation in lat. 51° 47′ N., long. 10° 34′ W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. Magnetic course from A to Smalls, S. 53° 2′ E., or S.E. ¾ E. Deviation 7° E. Compass course S. 60° 2′ E., or S.E. by E. ⅜ E., distance 60 miles.

II. Magnetic bearing Hook Point, N.E. ¾ N., or N. 36° 32′ E.; magnetic bearing, Saltees, E. ⅜ N., or N. 85° 45′ E. Latitude 51° 57′ N.; longitude 7° 1′ W.

III. 1st magnetic bearing, Saltees, N. 59° 2′ E., or N. E. by E. ¼ E.; 2nd magnetic bearing N. 9° 53′ W., or N. ⅞ W. Latitude 51° 50′ N.; longitude 6° 28′ W.; dist. 14¾ miles.

IV. True course S.E. by E., or S. 56° 15′ E.; magnetic course S.E. ⅞ E., or S. 34° 45′ E. Deviation 4° W. Compass course S. 30° 45′ E., or S.S.E. ¾ E., distance 31½ miles.

V. Standard Port for Reference—Waterford; constant for time + $0^h\,20^m$; constant for height + 0 ft. 6 in.; time of high water, Saltees, $0^h\,59^m$ P.M.; height, Saltees, 9 ft. 10 in.; time from high water $1^h\,59^m$; half spring range 6 ft. 6 in.; height above half tide 3 ft. 4 in.; $1^h\,59^m$ and 3 ft. 4 in. = correction + 1 ft. 8 in. Correction for sounding *subt.* 8 ft. 2 in.

13. **Star.**—Star's decl. 22° 55′ 55″ N., true alt. 60° 23′ 4″. *Latitude* 52° 32′ 51″ N. (*Norie*).
„ „ 60 22 57 „ 52 32 58 N. (*Raper*).

The Curve.—Correct magnetic bearing S. 100° W., or N. 80° W.

Deviations.—49° E., 16° E., 23° W., 54° W., 50° W., 11° W., 18° E., 54° E.

Compass courses.—S. 85° W., South, N. 39° W., S. 16½° W.

Magnetic courses.—N. 65° E., S. 27½° E., N. 5° W., S. 62° W.

Bearings, magnetic.—S. 46° E., S. 52° W., N. 35° E.

EXAMINATION PAPER—No. XXI, *Pages* 463-465.

1. 7·754166 = 56776104, $\bar{3}$·806197 = ·00640025.

2. 8·201561 = ·015906, 13·000000 = 10000000000000.

3. **True Courses.**—S. 6° W., 19′ dep. course; N. 50° W., 23′·7; S. 47° E., 16′·3; N. 18° E., 17′·6; S. 8° W., 14′·1; N. 87° E., 42′; S. 75° E., 12′; S. 65° W., 15′ current course. *Diff. lat.* 19′·3 S.; *dep.* 35′ E.; *course* S. 61° E.; *dist.* 40′ E. *Lat. in* 56° 41′ N.; *diff. long.* 64′ E. *Long. in* 38° 56′ W.

4. Green. date June $24^d\,20^h\,3^m$, red. decl. 23° 24′ 29″ N., true alt. 60° 4′ 7″. *Latitude* 6° 31′ 24″ S.

Raper: True alt. 60° 4′ 1″. *Latitude* 6° 31′ 30″ S.

5. *Diff. long.* 153′·9 W., or 2° 34′ W. *Longitude in* 12° 4′ W.

6. Diff. lat. 4528′·5 N.; mer. diff. lat. 4896′·5; diff. long. 3540′ E.; log. tang. 9·859117; *course* N. 35° 52′ E.; *distance* 5588′.

7. Standard, Queenstown, constant — $0^h\,59^m$; $10^h\,30^m$ A.M., and $11^h\,9^m$ P.M.
„ Galway „ + 0 22 ; 11 55 A.M., and no P.M.
„ Waterford „ + 0 44 ; no A.M., and 0 33 P.M.
Standard, Brest, constant, + $3^h\,42^m$; corr. for long. + 10^m; $1^h\,42^m$ A.M., and $2^h\,19^m$ P.M.

8. Green. date June $23^d\,18^h\,48^m\,12^s$; red. decl. 23° 25′ 48″ N.; true amp. 23° 25′ 48″ N. *Error of compass* 54° 22′ W. *Deviation* 32° 42′ W.

9. Interval 32^d; rate $0^s·8$ *gaining*; interval $113^d\,5^h$; accumulated rate — $1^m\,30^s·6$; Green. date Sept. $22^d\,4^h\,57^m\,35^s$; red. decl. 0° 15′ 33″ N.; true alt. 16° 56′ 12″; red. eq. T. — $7^m\,20^s$; hour-angle $4^h\,52^m\,15^s$; M.T. ship $21^d\,19^h\,0^m\,25^s$. *Longitude* 149° 17′ 30″ W.

Raper: True alt. 16° 56′ 5″; hour-angle $4^h\,52^m\,16^s$. *Longitude* 149° 17½′ W.

10. Green. date March $21^d\,13^h\,51^m\,16^s$; red. decl. 0° 27′ 11″ N.; true alt. 42° 57′ 18″; sum of logs. 19·623070; true azimuth N. 80° 46′ 23″ W. *Error* 14° 51′ 7″ E.; *deviation* 7° 1′ 7″ E.

Raper: True alt. 42° 57′ 14″; sine sq. 9·623074; true azimuth N. 80° 46′ 24″ W. *Error* 14° 51′ 6″ E; *deviation* 7° 1′ 6″ E.

Time azimuth: Red. eq. T. $7^m\,9^s·39$ *subt.* from M.T.; app. time at ship $3^h\,7^m\,51^s$ P.M.; *true azimuth* S. 98° 57′ W.; *error* 14° 34′ E.; *deviation* 6° 44′ E.

11. Time from noon $10^m 51^s$; Green. date October $3^d 14^h 27^m 9^s$; red. decl. 4° 10' 22" S.; true alt. 63° 47' 10"; nat. no. 964; mer. zen. dist. 26° 5' 19" S. *Latitude* 30° 15' 41" S.

METHOD II. Red. + 7' 30". (*Norie*) *Lat.* 30° 15' 42" S. (*Raper*) *Lat.* 30° 15' 45" S.

Towson: Aug. I + 0' 17"; index 15. Aug. II + 8' 3". *Latitude* 30° 15' 26" S.

12. 1st red. decl. 20° 53' 1" S.; 1st eq. T. + $10^m 5^s$; 1st true alt. 13° 18' 58"; lat. 49° 0' gives hour-angle $2^h 21^m 47^s$; long. 139° 55' W. (A). Lat. 49° 40' gives hour-angle $2^h 15^m 30^s$; long. 138° 20½' W. (A'). 2nd red. decl. 20° 51' 0" S.; 2nd red. eq. T. + $10^m 8^s$·3; lat. 49° 0' gives hour-angle $1^h 57^m 2^s$; long. 138° 44½' W. (B). Lat. 49° 40' gives hour-angle $1^h 49^m 7^s$; long. 140° 43½' W. (B'). The line of bearing at first observation trends N.E. by E. Sun's azimuth S. 34° E. Ship at second observation in lat. 49° 13' N.; long. 139° 23½' W. 2nd line of bearing, B B', N.W. by W. ½ W. (westerly). Azimuth S. 27° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from Manacles to Rame Head N.E. by E. ⅝ E., or N. 63° 17' E.; magnetic course N. 82° 47' E., or E. ⅝ N.; deviation 24° 30' W.; compass course S. 72° 43' E., or E. by S. ½ S., distance 35 miles.

II. True bearing St. Anthony's N. 86° 11' W. or W. ⅜ N. True bearing Dodman Point N. 44° W. or N.W. ⅛ N. Lat. 50° 7½' N. Long. 4° 38½' W.

III. 1st true bearing, St. Anthony's N. 66° 30' W., or N.W. by W. ⅞ W.; 2nd true bearing S. 79° 45' W., or W. ⅞ S. Lat. 50° 10½' N. Long. 4° 38' W. Distance 14½ miles.

IV. True course N.E. ¾ E., or N. 53° 26' E.; magnetic course N. 72° 56' E., or E. by N. ½ N. Deviation 23° W. Compass course S. 84° 4' E., or E. ½ S., dist. 21½ miles.

V. Standard Port for Reference—Devonport; constant for time — $0^h 46^m$; constant for height + 0 ft. 6 in.; time of high water, Falmouth, $11^h 9^m$ P.M.; height of high water, Falmouth, 12 ft. 7 in.; time from high water $3^h 9^m$; half spring range 8 ft. 0 in.; height above half tide 4 ft. 7 in.; $3^h 9^m$ and 4 ft. 7 in. = corr. — 0 ft. 4 in. Correction for sounding *subt.* 7 ft. 8 in.

13. Star.—Star's decl. 55° 54' 49" N.; true alt. 84° 56' 45". *Latitude* 60° 58' 4" N.

Raper: True alt. 84° 56' 39". *Latitude* 60° 58' 10" N.

The Curve.—Correct magnetic bearing N. 95° E., or S. 85° E.

Deviations.—7° W.; 17° W.; 29° W.; 24° W.; 4° E.; 29° E.; 28° E.; 16° E.

Compass courses.—N. 18½° E.; S. 60° E; S. 5½° E.; S. 58° W.

Magnetic courses.—N. 32½° E.; S. 40° E.; S. 58½° W.; N. 15° W.

Bearings, magnetic.—(Deviation for ship's head S.W. by W. ½ W. = 30° E.), N. 69½° E.; S. 65½° E..

EXAMINATION PAPER—No. XXII, *Pages* 465-467.

1. 6·055795 = 1137091·4; 6·717087 = 5213000.

2. 6·394281 = 2479022·7; 3·000000 = 1000.

3. True Courses.—N. 55° E., 25' dep. course; N. 49° W., 50'; N. 72° W., 38'; N. 80° W., 33'·8; N. 6° E., 37'·9; N. 3° W., 42'·5; N. 43° W., 29'; West, 32' current course. *Diff. lat.* 166'·0 N.; *dep.* 136'·6 W.; *course* N. 39½° W.; *dist.* 215½'. *Lat. in* 53° 54½' N.; *mid. lat.* 52° 31½' N.; *diff. long.* 224'·5. *Long. in* 2° 19½' W.

4. Green. date August $25^d 17^h 51^m 48^s$; red. decl. 10° 32' 6" N.; true alt. 35° 48' 58". *Latitude* 43° 38' 56" S.

Raper: True alt. 35° 48' 55". *Latitude* 43° 38' 59" S.

5. Log. of diff. long. 2·254252 = *diff. long.* 179'·6.

6. Diff. lat. 315' S.; mer. diff. lat. 524'; diff. long. 365'; tang. course 9·842962; *course* S. 34° 51' 35" E.; log. of *distance* 2·584204; *distance* 383'·9.

7. Standard; Hull, constant $-1^h 59^m$; $0^h 7^m$ A.M., and $6^h 37^m$ P.M.
„ Leith „ $-1\ 43$; 8 52 A.M., and 9 21 P.M.
„ Greenock „ $+4\ 41$; no A.M., and 0 19 P.M.
„ Weston-super-Mare „ $-2\ 10$; no A.M., and 0 23 P.M.
„ Thurso „ $-0\ 58$; 3 38 A.M., and 4 8 P.M.
„ Sunderland „ $+0\ 23$; 11 52 A.M., and no P.M.

8. Green. date, Sep. $22^d\ 19^h\ 50^m\ 52^s$; red. decl. 0° 1′ 11″ N.; log. sine 6·735350; true amp. W. 0° 1′ 52″ N.; *error of compass* 15° 1′ 52″ E.; *deviation* 5° 14′ 8″ W.

9. Interval 100^d; rate $4^s{\cdot}6$ *gaining*; interval $89^d\ 22\tfrac{1}{2}^h$; acc. rate $6^m\ 54^s$; Green. date Aug. $27^d\ 22^h\ 15^m\ 56^s$; red. decl. 9° 46′ 16″ N.; red. eq. T. $+1^m\ 10^s{\cdot}1$; true alt. 38° 15′ 44″; hour-angle 3° 19′ 5″; M.T. ship Aug. $28^d\ 3^h\ 20^m\ 15^s$. *Longitude* 76° 4′ 45″ E.

Raper: True alt. 38° 15′ 40″; hour-angle $3^h\ 19^m\ 5^s$. *Longitude* 76° 4′ 45″ E.

10. Green. date June $15^d\ 2^h\ 30^m\ 52^s$; red. decl. 23° 19′ 15″ N.; true alt. 9° 21′ 57″; sum of logs. 19·879589; true azimuth S. 121° 2′ 44″ W. *Error of compass* 61° 46′ 1″ W. *Deviation* 11° 6′ 1″ W.

Raper: True alt. 9° 21′ 42″; true azimuth S. 121° 3′ 15″ W. *Deviation* 11° 5′ 30″ W.

Time azimuth: Red. eq. T. — $0^m\ 8^s{\cdot}3$; app. time at ship $7^h\ 31^m\ 52^s$ P.M.; *true azimuth* N. 58° 58′ W.; *deviation* 11° 7′ W.

11. Time from noon $22^m\ 35^s$; Green. date Aug. $28^d\ 6^h\ 17^m\ 11^s$; red. decl. 9° 39′ 11″ N.; true alt. 26° 21′ 48″; nat. no. 1372; mer. zen. dist. 63° 32′ 56″ N. *Latitude* 73° 12′ 7″ N.

METHOD II. Red. + 5′ 16″; *latitude* 73° 12′ 7″ N., *Norie.* *Latitude* 73° 12′ 17″ N., *Raper.*

Towson: Aug. I + 2° 47′; index 58. Aug. II + 8′ 10″. *Latitude* 73° 12′ 0″ N.

12. 1st red. decl. 15° 59′ 0″ N.; 1st red. eq. T. $+5^m\ 21^s{\cdot}1$; true alt. 50° 40′ 55″; lat. 46° 30′ gives hour-angle $1^h\ 59^m\ 26^s$; long. 88° 28½′ E. (A). Lat. 46° 0′ gives hour-angle $2^h\ 1^m\ 53^s$; long. 87° 51¾′ E. (A′). 2nd red. decl. 15° 56′ 22″ N.; 2nd red. eq. T. $+5^m\ 20^s$; true alt. 53° 0′ 48″; lat. 46° 30′ gives hour-angle $1^h\ 40^m\ 15^s$; long. 88° 27′ E. (B). Lat. 46° 0′ gives hour-angle $1^h\ 43^m\ 18^s$; long. 89° 12¾′ E. (B′). The line of bearing at the first observation trends S.W. ½ S. Sun's true azimuth S. 51° E. Ship at second observation in lat. 46° 22′ N., long. 88° 40′ E. 2nd line of bearing, B B′, S.E. Azimuth S. 45° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. Magnetic course from Lizard to Start, E. ⅜ S., or S. 85° 58′ E.; deviation 25° W. Compass course S. 60° 58′ E., or S.E. by E. ⅜ E., distance 62 miles.

II. Magnetic bearing Lizard S. 73° 26′ W., or W. by S. ½ S.; magnetic bearing St. Anthony's N. 0° 19′ E., or North. Lat. 50° 4′ N. Long. 4° 57½′ W.

III. 1st magnetic bearing St. Anthony's N. 20° E., or N. by E. ¾ E.; 2nd magnetic bearing N. 70° W., or W. by N. ¾ N. Latitude 50° 8′ N. Longitude 4° 39′ W. Dist. 13 miles.

IV. Magnetic course E. ¼ S., or S. 87° 22′ E. Deviation 25° W. Compass course S. 62° 22′ E., or S.E. by E. ½ E., distance 34½ miles.

V. Standard Port for Reference—Devonport; constant for time — $0^h\ 43^m$; constant for height — 1 ft. 3 in.; time of high water Lizard $4^h\ 50^m$ A.M.; height at high water Lizard 14 ft. 8 in.; time from high water $2^h\ 4^m$; height above half tide 7 ft. 6 in.; $2^h\ 4^m$ and 7 ft. 6 in. = correction + 3 ft. 6 in.; half spring range 7 ft. 2 in. Correction for soundings *subt.* 10 ft. 8 in.

13. Star.—Star's decl. 55° 55′ 10″ N.; true alt. 62° 12′ 39″; *latitude* 28° 7′ 49″ N.

Raper: True alt. 62° 12′ 34″; *latitude* 28° 7′ 44″ N.

The Curve.—Correct magnetic bearing S. 30° W.

Deviations.—14° W., 15° W., 15° W., 10° W., 13° E., 30° E., 16° E., 5° W.

Compass courses.—S. 20½° W., N. 30° E., S. 55° E.

Magnetic courses.—S. 75° W., N. 74° W., N. 62° E.

Bearings, magnetic.—N. 14° W., N. 70° E.

EXAMINATION PAPER—No. XXIII, *Pages* 467-469.

1. 9·306425 = 2025000000; 7·417139 = 26130000.

2. 5·119223 = 131590; 5·903090 = 800000. 7·903090 = 80000000.

3. **True Courses.**—S. 24° W., 12' dep. course; S. 43° W., 34'; S. 57° W., 30'; S. 32° W., 32'; S. 1° W., 34'; S. 3° E., 32'; S. 19° E., 34'; S. 59° W., 30' current courses. *Diff. lat.* 192'·9 S.; *dep.* 83'·8 W.; *course* S. 23½° W., *dist.* 210½'. *Lat. in* 58° 57' N.; *mid. lat.* 60° 33'; *diff. long.* 170'·4 W. *Longitude in* 181° 42' W., or 178° 18' E.

4. Green. date Aug. $31^d\ 17^h\ 29^m\ 12^s$; red. decl. 8° 24' 43" N.; true alt. 51° 9' 26"; *latitude* 30° 25' 52" S.

Raper: True alt. 51° 9' 21". *Latitude* 30° 25' 56" S.

5. Log. of diff. long. 2·322530 = *diff. long.* 210'·2.

6. Diff. lat. 5968' N.; mer. diff. lat. 7050'; diff. long. 2121' W.; tang. 9·478352; *course* N. 16° 44' 38" W.; log. of distance 3·794644; *distance* 6232'.

7. Standard,	Brest,	constant	$+ 0^h 50^m$;	no	A.M., and $0^h 25^m$ P.M.
„	Devonport	„	$-0\ 46$;	no	A.M., and 0 23 P.M.
„	Hull	„	$-1\ 50$;	no	A.M., and 0 21 P.M.
„	Weston-super-mare	„	$-1\ 41$;	no	A.M., and 0 29 P.M.
„	Queenstown	„	$-0\ 25$;	no	A.M., and 0 9 P.M.
„	Brest	„	$+7\ 13$;	corr. long. $+11^m$,	$6^h 22^m$ A.M., $6^h 59^m$ P.M.

8. Green. date Dec. $24^d\ 1^h\ 14^m\ 12^s$; red. decl. 23° 25' 44" S.; sine 9·972428; true amp. E. 69° 47' 56" S. *Error of compass* 25° 43' 34" W.; *deviation* 27° 9' 34" W.

9. Interval $92^d\ 23^h$; acc. rate — $0^m\ 51^s$. Green. date April $14^d\ 22^h\ 29^m\ 49^s$; red. decl. 9° 43' 47" N.; true alt. 22° 23' 50"; red. eq. time $0^m\ 3^s{\cdot}8$ + hour-angle $4^h\ 27^m\ 51^s$; M.T. ship April $14^d\ 19^h\ 32^m\ 13^s$. *Longitude* 44° 24' 0" W.

Raper: True alt. 22° 23' 38"; hour-angle $4^h\ 27^m\ 52^s$. *Longitude* 44° 24' 15" W.

10. Green. date Sept. $22^d\ 16^h\ 6^m\ 20^s$, red. decl. 0° 4' 41" N., true alt. 32° 18' 38", sum of logs. 19·372396, true azimuth S. 58° 5' 30" W. *Error* 26° 17' 0" W. *Deviation* 6° 17' 0" W.

By *Raper:* True alt. 32° 18 33"; true azimuth S. 58° 5' 37" W. *Deviation* 6° 16' 53" W.

Time azimuth: Red. eq. T. $7^m\ 29^s{\cdot}27$, *add* to M.T.; app. time at ship $3^h\ 2^m\ 29^s$; *true azimuth* N. 122° 17' W. *Error* 26° 40' W. *Deviation* 6° 40' W.

11. Time from noon $12^m\ 18^s$; Green. date Sept. $22^d\ 8^h\ 11^m\ 12^s$; red. decl. 0° 12' 25" N.; true alt. 49° 31' 49"; nat. no. 1094; nat. cos. 761843; mer. zen. dist. 40° 22' 23" N. *Latitude* 40° 34' 48" N.

METHOD II. + 5' 48", *latitude* 40° 34' 48" N., *Norie*. *Latitude* 40° 34' 57" N., *Raper*.

Towson: Aug. I, + 1", index 19. Aug. II, + 5' 51"; *latitude* 40° 34' 46" N.

12. 1st red. decl. 20° 58' 18" S.; 1st red. eq. T. — $12^m\ 32^s{\cdot}3$; 1st true alt. 11° 27' 7"; lat. 49° 0' gives hour-angle $2^h\ 40^m\ 22^s$; long. 83° 2¼' W. (A). Lat. 49° 30' gives hour-angle $2^h\ 36^m\ 21^s$; long. 82° 2' W. (A'). 2nd red. decl. 21° 0' 17" S.; eq. T. — $12^m\ 29^s$; true alt. 16° 43' 47"; lat. 49° 0' gives hour-angle $1^h\ 37^m\ 2^s$; long. 81° 19' W. (B). Lat. 49° 30' gives hour-angle $1^h\ 29^m\ 43^s$; long. 83° 8¾' W. (B'). The line of bearing at the first observation trends N.E. ¾ E. Sun's azimuth S.E. ¾ S. (S. 37° E.) Ship at the second observation in lat. 49° 18½' N., long. 82° 26½' W. 2nd line of bearing, B B', W.N.W. Azimuth S. 22½° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from Bembridge Point to Fecamp, S.E. ⅛ E., or S. 46° 24' E.; magnetic course S. 28° 24' E., or S.S.E. ½ E.; deviation 8° 50' W.; compass course S. 19° 34' E., or S. by E. ¾ E., distance 78½ miles.

II. True bearing Nab, N. 18° 24' W., or N. by W. ⅝ W.; true bearing Owers, N. 74° 25' E., or E. by N. ⅜ N. Lat. 50° 36½' N., long. 0° 56' W.

III. 1st true bearing Owers, N. 54° 44′ E., N.E. ⅞ E ; 2nd true bearing N. 1° 18′ E., or N. ⅛ E. Lat. 50° 26′ N., long. 0° 42′ W., distance 12½ miles.

IV. True course S.E. ⅛ E., or S. 46° 24′ E.; magnetic course S. 28° 24′ E., or S.S.E. ½ E.; deviation 8° 50′ W.; compass course S. 19° 34′ E., or S. by E. ¾ E., distance 22½ miles.

V. Standard Port for Reference—Brest; constant for time + 6^h 57^m; constant for height + 4 ft. 2 in.; time of high water Fecamp 11^h 44^m A.M.; height at high water Fecamp 24 ft. 8 in.; time from high water 3^h 32^m; half spring range 11 ft. 9 in.; height above half tide 12 ft. 11 in.; 3^h 32^m and 12 ft. 11 in. = correction — 3 ft. 7 in. Correction for soundings *subt.* 8 ft. 2 in.

13. **Star.**—Decl. β Centauri 59° 49′ 54″ S.; true alt. 59° 41′ 53″. *Lat.* 29° 31′ 47″ S., *Norie.*
„ „ „ 59 41 44 „ 29 31 38 S., *Raper.*

The Curve.—Correct magnetic bearing N. 68° E.

Deviations.—34° W.; 0°; 31° E.; 32° E.; 24° E.; 1° E.; 22° W.; 32° W.

Compass courses.—N. 74½° E.; N. 45° E.; N. 13° E.; S. 6° E.

Magnetic courses.—S. 47° W.; S. 72½° W.; S. 17½° W.; N. 57½° E.

Bearings, magnetic.—Dev. 28° W.; S. 28° E.; N. 19½° W.

EXAMINATION PAPER—No. XXIV, *Pages* 469-471.

1. 6·996949 = 9930000. 8·059790 = ·011476.

2. 0·954243 = 9. 5·243038 = 175000.

3. **True Courses.**—S. 82° E., 42′ dep. course; S. 85° E., 53′; N. 86° E., 47′; South, 22′; N. 34° W., 14′; S. 84° E., 37′; S. 61° E, 35′; S. 82° E., 52′·5 current course. *Diff. lat.* 45′·7 S., *dep.* 252′·9 E.; *course* S. 80° E.; *dist.* 257′. *Lat. in* 36° 59′ N.; *diff. long.* 318′ E.; *long. in* 4° 20′ E.

4. Green. date November 30^d 19^h 28^m 16^s; red. decl. 21° 47′ 1″ S.; true alt. 18° 54′ 37″. *Lat.* 49° 18′ 22″ N.

Raper: True alt. 18° 54′ 27″. *Latitude* 49° 18′ 32″ N.

5. Log. of diff. long. 2·421932 = *Diff. long.* 264′·2.

6. Diff. lat. 1241′ N.; mer. diff. lat. 1252′; diff. long. 2117′ E.; tang. 10·228117; *course* N. 59° 23′ 59″ E.; *log. distance* = 3·387015; *distance* 2438′, nearly.

7.	Standard,	Brest	constant	+ 1^h 6^m;	0^h47^m A.M., and 1^h24^m P.M.
	„	Brest	„	— 0 26 ;	11 52 A.M., and no P.M.
	„	Brest	„	+ 2 45 ;	2 26 A.M., and 3 3 P.M.
	„	Devonport	„	— 1 13 ;	no A.M., and 0 25 P.M.
	„	Galway	„	+ 1 35 ;	2 16 A.M., and 2 49 P.M.
	„	Queenstown	„	— 1 4 ;	no A.M., and 0 12 P.M.
	„	Brest	„	+ 4 28 ;	corr. for long. —18^m, 3^h51^m A.M., 4^h28^m P.M.

8. Green. date February 1^d 17^h 13^m 59^s; red. decl. 16° 53′ 33″ S.; sine 9·996500; true amp. W. 82° 44′ 9″ S. *Error* 15° 42′ 6″ E.; *deviation* 20° 37′ 54″ W.

9. Interval 62^d; rate $2^s·5$ *losing*; interval 76^d 9^h; acc. rate + 3^m 11^s; Green. date August 31^d 9^h 11^m 56^s, red. decl. 8° 32′ 12″ N., red. eq. T. + 0^m $7^s·75$, true alt. 45° 14′ 40″, hour-angle 2^h 56^m 25^s, M.T. ship Aug. 31^d 2^h 56^m 33^s. *Longitude* 93° 50′ 45″ W.

Raper: True alt. 45° 14′ 31″; hour-angle 2^h 56^m 26^s. *Longitude* 93° 50′ 30″ W.

10. Green. date June 15^d 2^h 30^m 53^s; red. decl. 23° 19′ 15″ N.; true alt. 9° 21′ 57″; sum of logs. 19·864544; true azimuth S. 117° 39′ 10″ W. *Error* 65° 9′ 35″ W.; *deviation* 14° 29′ 35″ W.

Raper: True alt. 9° 21′ 43″; sine sq. 9·864571; true azimuth S. 117° 39′ 31″ W. *Deviation* 14° 29′ 14″ W.

Time azimuth: Red. eq. T. 0^m $8^s·33$ *subt.* from M.T.; app. time ship 7^h 11^m 33^s P.M.; *true azimuth* N. 62° 15′ W.; *error* 65° 4′ W.; *deviation* 14° 24′ W.

11. Time from noon 10^{m} 34^{s}; Green. date March 20^{d} 16^{h} 55^{m} 26^{s}; red. decl. 0° 6′ 39″ N.; true alt. 71° 18′ 34″; nat. no. 1004; mer. zen. dist. 18° 30′ 38″ N. *Latitude* 18° 37′ 17″ N.

METHOD II.—*Raper:* True alt. 71° 18′ 28″; red. + 10′ 46″; *latitude* 18° 37′ 24″ N.

Towson: Aug. I 0; index 14. Aug. II + 11′ 1″. *Latitude* 18° 37′ 4″ N.

12. 1st red. decl. 13° 40′ 6″ N.; 1st eq. T. + 4^{m} 3^{s}; true alt. 28° 25′ 3″; lat. 49° 30′ gives hour-angle 4^{h} 8^{m} 1^{s}; long. 178° 55½′ E. (A). Lat. 50° 0′ gives hour-angle 4^{h} 7^{m} 19^{s}; long. 179° 6′ E. (A′). 2nd red. decl. 13° 35′ 20″ N.; 2nd red. eq. T. + 4^{m} 0^{s}·3; true alt. 46° 32′ 43″; lat. 49° 30′ gives hour-angle 1^{h} 59^{m} 35^{s}; long. 180° 48¾′ E., or 179° 11¼′ W. (B). Lat. 50° 0′ gives hour-angle 1^{h} 56^{m} 24^{s}; long. 179° 59′ W. (B′). The line of bearing trends N. by E. (easterly). Sun's true bearing S. 77° E. Ship at second observation in lat. 50° 11½′ N., long. 179° 42′ E. 2nd line of bearing, BB′, N.W. (westerly). True Azimuth S. 44° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from Kinsale to Smalls E. ⅜ N., or N. 85° 47′ E.; magnetic course S. 72° 43′ E., or E. by S. ½ S. Deviation 24° 45′ W. Compass course S. 47° 58′ E., or S.E. ¼ E., distance 105½ miles.

II. True bearing of Daunt's Rock N. 60° 19′ W., or N.W. by W. ⅜ W.; true bearing Ballycottin N. 7° 11′ E., or N. ⅝ E.; latitude 51° 37½′ N.; longitude 8° 1⅛′ W.

III. 1st true bearing Ballycottin N. 38° 8′ E., or N.E. ⅝ N.; 2nd true bearing N. 35° W., or N.W. ⅞ N.; latitude 51° 38′ N.; longitude 7° 46′ W.; distance 14 miles.

IV. True course E. ⅜ S., or S. 85° 47′ E.; magnetic course S. 64° 17′ E., or S.E. by E. ¾ E.; deviation 23° W. Compass course S. 41° 17′ E., or S.E. ⅜ S.; distance 9¼ miles.

V. Standard Port for Reference—Waterford; constant for time — 0^{h} 26^{m}; constant for height — 0 ft. 5 in; time of high water, Ballycottin 8^{h} 6^{m} A.M.; height of high water Ballycottin 11 ft. 4 in.; time from high water 1^{h} 34^{m}; height above half tide 5 ft. 4 in.; half spring range 6 ft. 0 in.; 1^{h} 34^{m} and 5 ft. 4 in. = correction + 3 ft. 8 in. Correction for sounding *subt.* 9 ft. 8 in.

13. Star.—Markab's decl. 14° 35′ 44″ N.; true alt. 33° 16′ 27″. *Lat.* 42° 7′ 49″ S., *Norie.*
„ „ „ 33 16 21 „ 42 7 55 S., *Raper.*

The Curve.—Correct magnetic bearing N. 20° 30′ E.

Deviations.—3½° E.; 27½° E.; 29½° E.; 26½° E.; 4½° W.; 24½° W.; 31½° W.; 20½° W.

Compass courses.—N. 68½° E.; N. 47° W.; S. 71° E.; N. 77° W.

Magnetic courses.—N. 65° E.; N. 6° W.; S. 3° E.; S. 65° W.

Bearings, magnetic.—Dev. 28° W. N. 70½° E.; S. 22° E.

EXAMINATION PAPER—No. XXV, *Pages* 471-473.

1. 6·742037 = 5521240·5. 5·109096 = 128557.

2. $\bar{1}$·903505 = ·800767. 4·648461 = 44510·31.

3. True Courses.—N. 2° W., 21′ dep. course; N. 51° E., 16′·6; S. 25° W., 13′·4; N. 5° W., 19′·3; S. 57° W., 19′·1; N. 70° W., 48′; N. 33° E., 21′·3; N. 48° W., 49′ current course. Diff. lat. 95′·3 N., dep. 8′·3 W. Course N. 5° W., dist. 96′. *Lat. in* 63° 55′ N., *mid. lat.* 63° 7′; *diff. long.* 18′ W. *Long. in* 64° 58′ W.

4. Green. date May 31^{d} 21^{h} 1^{m} 20^{s}; red. decl. 22° 2′ 8″ N.; true alt. 72° 28′ 57″. *Lat.* 4° 31′ 5″ N. *Raper:* True alt. 72° 28′ 57″; *latitude* 4° 31′ 5″ N.

5. Log. of diff. long. 1·801088 = *Diff. long.* 63·25. *Long. in* 179° 11′ 45″ E.

6. Diff. lat. 3757′ S.; mer. diff. lat. 4255′; diff. long. 7560′ E.; log. tangent 10·249262; *course* S. 60° 37′ 40″ E.; *log. dist.* 3·884219; *distance* 7660′.

7. Standard, Leith	constant	— $1^h 17^m$;	$11^h 59^m$ A.M., and	no	P.M.
" Leith	"	— 0 52 ;	no A.M., and	$0^h 24^m$	P.M.
" London	"	— 2 19 ;	10 25 A.M., and	10 53	P.M.
" Brest	"	+ 6 57 ;	9 18 A.M., and	9 44	P.M.
" Sheerness	"	— 0 18 ;	11 45 A.M., and	no	P.M.

8. Green. date Dec. $21^d\ 17^h\ 30^m\ 48^s$; red. decl. 23° 27′ 2″ S.; true amp. W. 84° 5½′ S. *Error of compass* 14° 20½′ E.; *deviation* 13° 49½′ W.

9. Green. date Jan. $28^d\ 16^h\ 36^m\ 50^s{\cdot}6$; red. decl. 18° 0′ 52″ S.; red. eq. T. + $13^m\ 18^s{\cdot}5$; true alt. 17° 52′ 42″; D. lat. made since noon 11′ 6″ *added* to lat. at noon (28° 45′) gives lat. at sights 28° 56′ 6″ N., hour-angle $3^h\ 46^m\ 54^s$. *Long. at sight* 170° 50′ 30″ E., *diff. long. since noon* 18′ 57″ W. *Subt.* from long at sights as the ship was farther East at noon. *Long. at noon* 171° 9′ 27″ E.

Raper: True alt. 17° 52′ 28″; hour-angle $3^h\ 46^m\ 55^s$. *Longitude* 170° 50′ 45″ E., and at noon 171° 9′ 42″ E.

10. Green. date July $9^d\ 17^h\ 50^m\ 10^s$; red. decl. 22° 17′ 31″ N.; true alt. 14° 36′ 40″; sum of logs. 19·173774; true azimuth N. 45° 26′ 42″ W. *Error of compass* 47° 41′ 42″ W.; *deviation* 54° 26′ 42″ W.

Raper: True alt. 14° 36′ 31″; sine sq. 9·173828; true azimuth N. 45° 26′ 52″ W. *Deviation* 54° 26′ 52″ W.

Time Azimuth: Red. eq. T. $4^m\ 59^s{\cdot}53$ *subt.* from M.T.; app. time ship $3^h\ 9^m\ 2^s$ P.M.; *true azimuth* S. 135° 14′ W.; *error* 47° 1′ W.; *deviation* 53° 46′ W.

11. Green. date Nov. $28^d\ 15^h\ 58^m\ 31^s$, time from noon $12^m\ 11^s$, red. decl. 21° 25′ 52″ S., true alt. 74° 15′ 50″; nat. no. 1307; mer. zen. dist. 15° 27′ 28″ N. *Latitude* 5° 58′ 24″ S.

METHOD II. Red. + 17′ 15″. *Norie: latitude* 5° 58′ 57″ S. *Raper: latitude* 5° 58′ 53″ S.

Towson: Aug. I + 1′ 39″; index 16. Aug. II + 15′ 5″. *Latitude* 5° 58′ 26″ S.

12. 1st red. decl. 10° 13′ 14″ S.; 1st red. eq. T. — $15^m\ 3^s{\cdot}36$; 1st true alt. 29° 47′ 31″; lat. 49° 20′ gives hour-angle $0^h\ 40^m\ 16^s$; long. 118° 34½′ E. (A). Lat. 49° 50′ gives hour-angle $0^h\ 19^m\ 39^s$; long. 113° 25½ E. (A′). 2nd red. decl. 10° 16′ 8″ S.; 2nd eq. T. — $15^m\ 4^s{\cdot}7$; 2nd true alt. 12° 28′ 40″. Lat. 49° 20′ gives hour-angle $3^h\ 47^m\ 8^s$; long. 116° 48½′ E. (B). Lat. 49° 50′ gives hour-angle $3^h\ 45^m\ 8^s$; long. 116° 18½′ E. (B′). The line of bearing at first observation trends W. ¾ N. Sun's true bearing S. ¾ W. (or S. 8½° W.) 2nd line of bearing, B B′, N.W. by N.; azimuth S. 56½° W. Ship at second observation in lat. 49° 57′ N., long. 116° 12′ E.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from Lundy to Breaksea Point E. by N. ⅜ N., or N. 74° 32′ E.; magnetic course S. 83° 58′ E, or E. ½ S. Deviation 25° W. Compass course S. 58° 58′ E., or S.E. by E. ¼ E., distance 49 miles.

II. True bearing Ilfracombe S. 51° 56′ W., or S.W. ⅝ W.; true bearing of Scarweather N. 12° 34′ E., or N. by E. ⅛ E. Latitude 51° 17′ N.; longitude 3° 59½′ W.

III. 1st true bearing Scarweather N. 29° 26′ E., or N.N.E. ⅝ E.; 2nd true bearing N. 52° 8′ W., or N.W. ⅝ W. Lat. 51° 20′ N.; Long. 3° 42′ W.; distance 11 miles.

IV. True course E. by N. ⅜ N., or N. 74° 32′ E. Magnetic course S. 83° 58′ E, or E. ½ S. Deviation 25° W. Compass course S. 58° 58′ E., or S.E. by E. ¼ E., dist. 12 miles.

V. Standard Port for Reference—Weston-super-Mare; constant for time — $0^h\ 29^m$; constant for height — 4 ft. 0 in.; time of high water Nash $0^h\ 48^m$ P.M.; height of high water Nash 26 ft. 0 in.; time from high water $2^h\ 20^m$; height above half tide 9 ft. 6 in.; half spring range 16 ft. 6 in.; $2^h\ 30^m$ and 9 ft. 6 in. = correction + 3 ft. 3 in. Correction for sounding subt. 12 ft. 9 in.

13. **Star.**—β Orionis' decl. 8° 20′ 11″ S., true alt. 52° 11′ 54″; *latitude* 29° 27′ 55″ N., *Norie.*

Raper: True alt. 52° 11′ 45″; *latitude* 29° 28′ 4″ N.

The Curve.—Correct magnetic bearing S. 8° E.

Deviations.—15° E., 3° E., 13° W., 28° W., 14° W., 10° E., 13° E., 14° E.

Compass courses.—S. by W., S. 87° E., S. 13° E., S. 85½° W.

Magnetic courses.—N. 20° W., N. 54° W., S. 82° E., N. 32° E.

Bearings, magnetic.—S. 68° W.; West.

EXAMINATION PAPER—No. XXVI, *Pages* 473-475.

1. 7·891486 = 77890714; $\bar{8}$·763323 = ·000000057986.

2. 2·900314 = 794·904; 7·937469 = 86590100.

3. **True Courses.**—East, 39′ dep. course; S. 88° E., 54′·2; N. 48° E., 41′·6; S. 76° W., 14′·4; S. 22° E., 46′·5; N. 9° W., 29′·1; S. 51° E., 49′·2; N. 79° E., 40′·8 current course. *Diff. lat.* 15′·2 S.; *dep.* 192′·2 E.; *course* S. 85½° E.; *dist.* 193′. *Lat. in* 59° 34′ N.; *diff. long.* 380′·9 E. *Longitude in* 37° 49′ W.

4. Green. date Sept. 30^d 18^h 21^m 20^s; red. decl. 3° 4′ 25″ S.; true alt. 56° 56′ 24″. *Lat.* 29° 59′ 10″ N.

By *Raper:* True alt. 56° 56′ 15″. *Latitude* 29° 59′ 19″ N.

4*. Green. date July 2^d 8^h 59^m, red. decl. 23° 1′ 46″ N., true alt. 10° 25′ 59″: *latitude* 77° 24′ 13″ N.

Raper: True alt. 10° 25′ 52″, *latitude* 77° 24′ 6″ N.

* When the sun is observed below the pole (at midnight), instead of subtracting the true alt. from 90° add 90° to it, and from sum subtract declination. The lat. will be of the same name as the declination.

5. Log. D. long. 2·567880; diff. long. 369′·7 E., or 6° 10′ E., *long. in* 21° 18′ W.

6. Diff. lat. 5585′ N.; mer. diff. lat. 6325′; diff. long. 51′ W.; log. tang. 7·906510; *true course* N. 0° 27′ 43″ W.; log. dist. 3·747037 = distance 5585′.

7. Standard, Brest constant — 0^{h}17^m; 11^{h}27^{m}A.M., and midnight.
„ Brest „ + 0 50 ; 0 0 A.M., and 0^{h}34^{m}P.M.
„ Sunderland „ + 0 49 ; no A.M., and 0 4 P.M.
„ Sunderland „ — 0 52 ; 10 23 A.M., and 10 53 P.M.
„ Leith „ — 0 52 ; 9 30 A.M., and 10 0 P.M.
„ Brert „ — 1 17 ; corr. long. — 1^m: 10^h 26^m A.M., 10^h 59^m P.M.

8. Green. date April 25^d 0^h 34^m 48^s; red. decl. 13° 11′ 3″ N.; sine 9·625504; true amp W. 24° 58′ 22″ N. *Error* 67° 50′ 23″ W.; *deviation* 32° 0′ 23″ W.

9. Green. date Aug. 23^d 18^h 16^m 50^s; red. decl. 11° 13′ 7″ N.; red. eq. time + 2^m 19^s·4; true alt. 37° 26′ 50″; *lat. at sight* 37° 38′ 18″ N.; hour-angle 3^h 23^m 51^s. *Longitude at sight* 35° 24′ 30″ E., *diff. long.* 10° 51′ W., *long. at noon* 35° 13′ 39″ E.

Raper: True alt. 37° 26′ 42″; hour-angle 3^h 23^m 52^s. *Longitude* 35° 24′ 15″ E.; *long. at noon* 35° 13′ 24″ E.

10. Green. date Oct. 31^d 22^h 3^m 25^s; red. decl. 14° 24′ 14″ S.; true alt. 12° 23′ 17″; sum of logs. 19·225100; true azimuth S. 48° 22′ 54″ E. *Error* 51° 11′ 39″ W.; *deviation* 17° 51′ 39″ W.

Raper: True alt. 12° 23′ 9″; sine sq. 9·225168; true azimuth S. 48° 23′ 10″ E. *Deviation* 17° 51′ 55″ W.

Time azimuth: Red. eq. T. 16^m 18^s·3 *add* to M.T.; app. time at ship 8^h 43^m 59^s A.M.; *true azimuth* N. 131° 35′ E.; *error* 51° 14′ W.; *deviation* 17° 54′ W.

11. Green. date May 29^d 9^h 58^m 28^s; time from noon 4^m 12^s; red. decl. 21° 40′ 45″ N.; true alt. 67° 53′ 12″; nat. no. 156; mer. zen. dist. 22° 5′ 22″ S. *Latitude* 0° 24′ 37″ S.

Method II. Red. + 1′ 25″; *latitude* 0° 24′ 38″ S., *Norie.* *Latitude* 0° 24′ 42″ S., *Raper.*

Towson: Aug. I, + 0′ 12″; index 2. Aug. II, + 1′ 18″. *Latitude* 0° 24′ 33″ S.

12. 1st red. decl. 19° 2′ 59″ S.; 1st eq. T. — $14^m 52^s$; 1st true alt. 16° 58′ 37″; lat. 45° 55′ gives hour-angle $2^h 27^m 16^s$; long. 126° 35′ W. (A.) Lat. 46° 15′ gives hour-angel $2^h 24^m 38^s$; long. 125° 55½′ W. (A′). 2nd red. decl. 19° 6′ 22″ S.; 2nd eq. T. — $14^m 49^s$; 2nd true alt. 12° 17′ 8″. Lat. 45° 55′ gives hour-angle $3^h 8^m 12^s$; long. 125° 33¼′ W. (B). Lat. 46' 15′ gives hour-angle $3^h 6^m 16^s$; long. 126° 2¼′ W. (B′). The line of bearing at the first observation trends N.E. ¾ E. Sun's true bearing S.E. ¾ S., or S. 36½° E. The position of the ship at the second observation is lat. 45° 59′ N., long. 125° 39¼′ W. 2nd line of bearing, BB′, N.W. (nearly). Azimuth S. 46° W.

EXAMINATION IN CHART.

For all grades where the Chart is used.

I. True course from Seven Stones to Lundy Island N.E. ½ N., or N. 39° 23′ E.; magnetic course N. 60° 53′ E., or N.E. by E. ⅜ E. Dev. 20° 30′ W. Compass course N. 81° 23′ E., or E. ¾ N., distance 83½ miles.

II. True bearing, Longships, N. 25° 30′ E., or N.N.E. ¼ E.; true bearing Trevose Head N. 73° 19′ E., or E. by N. ½ N. Latitude 50° 27¼′ N. Longitude 5° 28′ W.

III. 1st true bearing Trevose Head N. 81° 45′ E., or E. ¾ N.; 2nd true bearing S. 16° 41′ E., or S. by E. ½ E. Lat. 50° 48′ N. Long. 5° 9′ W., distance 16 miles.

IV. Current set N. ¾ E., or N. 8° 51′ E. (magnetic): true course N.E. by E. ¼ E., or N. 59° 4′ E.; magnetic course N. 80° 34′ E., or E. ⅞ N. Dev. 24° 45′ W. Compass course S. 74° 41′ E., or E. by S. ⅜ S., distance 24½ miles.

V. Standard Port for Reference—Pembroke; constant for time — $0^h 32^m$; constant for height + 6 ft. 0 in.; time of high water, Caldy Road, $0^h 19^m$ A.M.; height at high water, Caldy 22 ft. 8 in.; time from high water $3^h 58^m$; half spring range 13 ft. 6 in.; height above half tide 9 ft. 2 in.; $3^h 58^m$ and 9 ft. 2 in. = corr. + 4 ft. 5 in. *Correction* for sounding *subt.* 9 ft. 1 in.

13. **Star.**—*α* Serpentis' decl. 6° 46′ 58″ N., true alt. 28' 58′ 36″; *lat.* 54° 14′ 26″ S., *Norie.*
" 54 14 37 S., *Raper.*

The Curve.—Correct magnetic bearing West.

Deviations.—50° W.; 10° W.; 18° E.; 54° E.; 49° E.; 16° E.; 23° W.; 54° W.

Compass courses.—S. 44½° E.; N. 8° E.; N. 86° E.; N. 35° E.

Magnetic courses.—N. 45½° W.; S. 16° W.; S. 71° W.; S. 49° W.

Bearings, magnetic.—Dev. 51½° E. S. 47° E.; N. 34° E.

SOUTH SHIELDS:
THOMAS L. AINSLEY, PRINTER, MILL DAM.

THE

REQUISITE ELEMENTS

FROM THE

NAUTICAL ALMANAC

FOR THE YEAR

1887,

FOR

EXERCISES

IN

AINSLEY'S GUIDE BOOK.

SOUTH SHIELDS:
Printed and Published by THOS. L. AINSLEY,
Mill Dam.

PRICE (separately) SIXPENCE.

ELEMENTS FROM THE NAUTICAL ALMANAC

FOR

AINSLEY'S GUIDE BOOK

For 1887.

SUN'S DECLINATION; SUN'S SEMIDIAMETER; EQUATION OF TIME.

(The Elements on the *left* of the double column are from page I of Nautical Almanac, those on the *right* from page II. Also the signs + and — to the left of the Equation of Time, indicates its application to *Apparent Time*.)

Apparent Noon. (N.A., p. I.)			**Mean Noon. (N.A., p. II.)**			
DATE.	DECLINATION.	VAR. IN ONE HOUR.	DECLINATION.	SUN'S SEMID.	EQUATION OF TIME.	VAR. IN ONE HOUR.
1887.	° ′ ″	″	° ′ ″	′ ″	M S	S
Jan. 1	S. 23 0 37·8	12·41	S. 23 0 38·6	16 18·2	+ 3 46·61	1·182
2	22 55 26·2	13·55	22 55 27·2	16 18·2	4 14·80	1·167
3	22 49 47·2	14·69	22 49 48·4	16 18·2	4 42·62	1·151
4	22 43 41·0	15·82	22 43 42·3	16 18·2	5 10·03	1·134
5	22 37 7·7	16·95	22 37 9·3	16 18·2	5 37·01	1·115
6	22 30 7·5	18·06	22 30 9·4	16 18·2	6 3·53	1·095
7	22 22 40·8	19·16	22 22 42·8	16 18·1	6 29·57	1·075
8	22 14 47·6	20·26	22 14 49·9	16 18·1	6 55·10	1·053
9	22 6 28·2	21·35	22 6 30·8	16 18·1	7 20·10	1·030
10	21 57 42·9	22·42	21 57 45·8	16 18·0	7 44·54	1·007
11	21 48 31·9	23·49	21 48 35·1	16 18·0	8 8·42	0·983
12	21 38 55·5	24·54	21 38 58·9	16 17·9	8 31·70	0·958
13	21 28 53·9	25·59	21 28 57·6	16 17·8	8 54·38	0·932
14	21 18 27·4	26·62	21 18 31·5	16 17·8	9 16·43	0·906
15	21 7 36·3	27·64	21 7 40·7	16 17·7	9 37·85	0·879
16	20 56 20·9	28·64	20 56 25·6	16 17·6	9 58·62	0·851
17	20 44 41·5	29·64	20 44 46·5	16 17·5	10 18·71	0·823
18	20 32 38·4	30·61	20 32 43·8	16 17·5	10 38·12	0·794
19	20 20 12·0	31·58	20 20 17·7	16 17·4	10 56·82	0·764
20	20 7 22·6	32·53	20 7 28·7	16 17·3	11 14·81	0·734
21	19 54 10·6	33·46	19 54 17·0	16 17·2	11 32·05	0·703
22	19 40 36·3	34·38	19 40 43·1	16 17·1	11 48·54	0·671
23	19 26 40·2	35·29	19 26 47·3	16 17·0	12 4·26	0·639
24	19 12 22·5	36·18	19 12 29 9	16 16·8	12 19·20	0·605
25	18 57 43·7	37·05	18 57 51·5	16 16·7	12 33·33	0·572
26	18 42 44·1	37·91	18 42 52·2	16 16·6	12 46·66	0·538
27	18 27 24·2	38·75	18 27 32·6	16 16·5	12 59·17	0·504
28	18 11 44·3	39·57	18 11 53·0	16 16·4	13 10 86	0·469
29	17 55 44·8	40·38	17 55 53·8	16 16·2	13 21·71	0·435
30	17 39 26·2	41·17	17 39 35·5	16 16·1	13 31·73	0·400
31	S. 17 22 48·7	41·94	S. 17 22 58·3	16 16·0	+ 13 40·91	0·365

Apparent Noon. (N.A., p. I).			**Mean Noon. (N.A., p. II.)**			
DATE.	DECLINATION.	VAR. IN ONE HOUR.	DECLINATION.	SUN'S SEMID.	EQUATION OF TIME.	VAR. IN ONE HOUR.
1887.	° ′ ″	″	° ′ ″	′ ″	M S	S
Feb. 1	S. 17 5 52·9	42·70	S. 17 6 2·7	16 15·8	+ 13 49·26	0·330
2	16 48 39·1	43·44	16 48 49·2	16 15·7	13 56·77	0·295
3	16 31 7·8	44·16	16 31 18·1	16 15·5	14 3·44	0·260
4	16 13 19·4	44·87	16 13 29·9	16 15·4	14 9·27	0·225
5	15 55 14·2	45·56	15 55 25·0	16 15·2	14 14·28	0·191
6	15 36 52·7	46·22	15 37 3·7	16 15·1	14 18·46	0·157
7	15 18 15·4	46·88	15 18 26·6	16 14·9	14 21·82	0·123
8	14 59 22·5	47·52	14 59 33·9	16 14·7	14 24·37	0·089
9	14 40 14·5	48·14	14 40 26·1	16 14·5	14 26·13	0·057
10	14 20 51·9	48·74	14 21 3·6	16 14·3	14 27·10	0·024
11	14 1 14·9	49·33	14 1 26·8	16 14·2	14 27·31	0·008
12	13 41 24·0	49·90	13 41 36·0	16 14·0	14 26·76	0·039
13	13 21 19·5	50·46	13 21 31·7	16 13·8	14 25·47	0·069
14	13 1 1·9	51·00	13 1 14·2	16 13·6	14 23·45	0·099
15	12 40 31·7	51·51	12 40 44·0	16 13·4	14 20·73	0·129
16	12 19 49·2	52·02	12 20 1·6	16 13·1	14 17·30	0·158
17	11 58 54·7	52·51	11 59 7·2	16 12·9	14 13·17	0·187
18	11 37 48·8	52·97	11 38 1·3	16 12·7	14 8·36	0·215
19	11 16 32·0	53·42	11 16 44·5	16 12·5	14 2·87	0·243
20	10 55 4·6	53·86	10 55 17·1	16 12·3	13 56·72	0·270
21	10 33 26·9	54·27	10 33 39·4	16 12·1	13 49·92	0·297
22	10 11 39·6	54·67	10 11 52·0	16 11·8	13 42·47	0·324
23	9 49 42·9	55·05	9 49 55·3	16 11·6	13 34·39	0·350
24	9 27 37·3	55·41	9 27 49·7	16 11·4	13 25·70	0·375
25	9 5 23·2	55·76	9 5 35·5	16 11·2	13 16·40	0·400
26	8 43 1·0	56·09	8 43 13·2	16 10·9	13 6·52	0·424
27	8 20 31·1	56·40	8 20 43·3	16 10·7	12 56·06	0·448
28	7 57 54·0	56·69	7 58 6·0	16 10·4	12 45·05	0·470
March 1	7 35 10·0	56·97	7 35 21·9	16 10·2	12 33·49	0·493
2	7 12 19·5	57·23	7 12 31·3	16 10·0	12 21·41	0·514
3	6 49 23·0	57·47	6 49 34·7	16 9·7	12 8·82	0·535
4	6 26 20·9	57·70	6 26 32·4	16 9·5	11 55·74	0·555
5	6 3 13·6	57·91	6 3 24·9	16 9·3	11 42·19	0·574
6	5 40 1·4	58·10	5 40 12·5	16 9·0	11 28·19	0·592
7	5 16 44·7	58·28	5 16 55·6	16 8·8	11 13·76	0·610
8	4 53 23·9	58·45	4 53 34·6	16 8·5	10 58·91	0·627
9	4 29 59·3	58·59	4 30 9·8	16 8·2	10 43·68	0·642
10	4 6 31·4	58·72	4 6 41·7	16 8·0	10 28·09	0·656
11	3 43 0·5	58·85	3 43 10·5	16 7·7	10 12·17	0·670
12	3 19 26·8	58·95	3 19 36·6	16 7·4	9 55·94	0·682
13	2 55 50·8	59·04	2 56 0·3	16 7·2	9 39·43	0·693
14	2 32 12·8	59·12	2 32 22·1	16 6·9	9 22·66	0·704
15	2 8 33·2	59·18	2 8 42·2	16 6·6	9 5·66	0·713
16	1 44 52·3	59·22	1 45 1·0	16 6·4	8 48·45	0·721
17	1 21 10·5	59·25	1 21 18·9	16 6·1	8 31·04	0·729
18	0 57 28·1	59·27	0 57 36·3	16 5·8	8 13·46	0·736
19	0 33 45·7	59·26	0 33 53·5	16 5·5	7 55·71	0·742
20	S. 0 10 3·4	59·25	S. 0 10 10·9	16 5·3	7 37·83	0·747
21	N. 0 13 38·3	59·22	N. 0 13 31·0	16 5·0	7 19·82	0·752
22	0 37 19·0	59·17	0 37 12·0	16 4·7	7 1·71	0·756
23	1 0 58·3	59·10	1 0 51·7	16 4·4	6 43·51	0·760
24	1 24 36·0	59·03	1 24 29·7	16 4·2	6 25·24	0·762
25	1 48 11·6	58·93	1 48 5·6	16 3·9	6 6·92	0·764
26	2 11 44·7	58·82	2 11 39·0	16 3·6	5 48·57	0·765
27	2 35 15·1	58·70	2 35 9·7	16 3·3	5 30·20	0·765
28	N. 2 58 42·2	58·56	N. 2 58 37·2	16 3·0	+ 5 11·83	0·765

Apparent Noon. (N.A., p. I.)			Mean Noon. (N.A., p. II).			
DATE.	DECLINATION.	VAR. IN ONE HOUR.	DECLINATION.	SUN'S SEMID.	EQUATION OF TIME.	VAR. IN ONE HOUR.
1887.	° ′ ″	″	° ′ ″	′ ″	M S	S
March 29	N. 3 22 5·8	58·40	N. 3 22 1·1	16 2·8	+ 4 53·49	0·764
30	3 45 25·6	58·23	3 45 21·1	16 2·5	4 35·18	0·762
31	4 8 41·0	58·05	4 8 36·9	16 2·2	4 16·92	0·759
April 1	4 31 51·8	57·85	4 31 48·0	16 2·0	3 58·73	0·756
2	4 54 57·7	57·63	4 54 54·1	16 1·7	3 40·63	0·752
3	5 17 58·2	57·40	5 17 54·9	16 1·4	3 22·64	0·747
4	5 40 52·9	57·16	5 40 50·0	16 1·2	3 4·77	0·741
5	6 3 41·7	56·90	6 3 39·1	16 0·9	2 47·05	0·735
6	6 26 24·1	56·63	6 26 21·7	16 0·6	2 29·49	0·727
7	6 48 59·8	56·34	6 48 57·7	16 0·3	2 12·12	0·719
8	7 11 28·5	56·04	7 11 26·7	16 0·1	1 54·97	0·710
9	7 33 49·9	55·73	7 33 48·4	15 59·8	1 38·06	0·699
10	7 56 3·7	55·41	7 56 2·5	15 59·5	1 21·42	0·687
11	8 18 9·6	55·08	8 18 8·6	15 59·2	1 5·06	0·675
12	8 40 7·3	54·72	8 40 6·5	15 59·0	0 49·00	0·662
13	9 1 56·3	54·36	9 1 55·8	15 58·7	0 33·27	0·648
14	9 23 36·5	53·98	9 23 36·3	15 58·4	0 17·88	0·634
15	9 45 7·5	53·59	9 45 7·5	15 58·1	+ 0 2·84	0·619
16	10 6 28·9	53·19	10 6 29·0	15 57·9	− 0 11·84	0·603
17	10 27 40·4	52·76	10 27 40·7	15 57·6	0 26·13	0·587
18	10 48 41·6	52·33	10 48 42·2	15 57·3	0 40·03	0·570
19	11 9 32·2	51·88	11 9 33·0	15 57·1	0 53·52	0·553
20	11 30 11·9	51·42	11 30 12·9	15 56·8	1 6·59	0·535
21	11 50 40·3	50·94	11 50 41·4	15 56·5	1 19·22	0·517
22	12 10 57·1	50·45	12 10 58·4	15 56·3	1 31·42	0·499
23	12 31 2·0	49·95	12 31 3·4	15 56·0	1 43·16	0·479
24	12 50 54·5	49·43	12 50 56·1	15 55·8	1 54·44	0·460
25	13 10 34·5	48·90	13 10 36·2	15 55·5	2 5·24	0·440
26	13 30 1·5	48·35	13 30 3·3	15 55·3	2 15·57	0·420
27	13 49 15·1	47·78	13 49 17·0	15 55·0	2 25·41	0·400
28	14 8 15·1	47·21	14 8 17·1	15 54·8	2 34·77	0·379
29	14 27 1·2	46·62	14 27 3·3	15 54·6	2 43·63	0·359
30	14 45 32·9	46·01	14 45 35·1	15 54·3	2 51·98	0·338
May 1	15 3 49·9	45·40	15 3 52·2	15 54·1	2 59·83	0·316
2	15 21 52·0	44·77	15 21 54·3	15 53·9	3 7·17	0·294
3	15 39 38·8	44·12	15 39 41·1	15 53·6	3 13·98	0·273
4	15 57 9·9	43·47	15 57 12·3	15 53·4	3 20·26	0·250
5	16 14 25·2	42·80	16 14 27·6	15 53·2	3 26·00	0·228
6	16 31 24·2	42·11	16 31 26·7	15 53·0	3 31·19	0·205
7	16 48 6·7	41·42	16 48 9·2	15 52·7	3 35·82	0·181
8	17 4 32·5	40·72	17 4 35·0	15 52·5	3 39·88	0·157
9	17 20 41·3	40·01	17 20 43·8	15 52·3	3 43·35	0·133
10	17 36 32·8	39·28	17 36 35·2	15 52·1	3 46·24	0·108
11	17 52 6·6	38·54	17 52 9·1	15 51·9	3 48·55	0·084
12	18 7 22·6	37·79	18 7 25·1	15 51·7	3 50·26	0·059
13	18 22 20·5	37·03	18 22 22·9	15 51·5	3 51·38	0·034
14	18 36 59·9	36·25	18 37 2·2	15 51·3	3 51·92	0·010
15	18 51 20·6	35·46	18 51 22·9	15 51·0	3 51·86	0·014
16	19 5 22·2	34·67	19 5 24·5	15 50·8	3 51·22	0·039
17	19 19 4·6	33·86	19 19 6·8	15 50·6	3 50·00	0·063
18	19 32 27·4	33·04	19 32 29·5	15 50·4	3 48·20	0·087
19	19 45 30·3	32·20	19 45 32·4	15 50·3	3 45·83	0·110
20	19 58 13·2	31·36	19 58 15·1	15 50·1	3 42·90	0·134
21	20 10 35·7	30·51	20 10 37·5	15 49·9	3 39·41	0·157
22	20 22 37·6	29·64	20 22 39·3	15 49·7	3 35·37	0·179
23	N. 20 34 18·6	28·77	N. 20 34 20·3	15 49·5	− 3 30·81	0·201

Apparent Noon. (N.A., p. I.)			Mean Noon. (N.A., p. II.)			
DATE.	DECLINATION.	VAR. IN ONE HOUR.	DECLINATION.	SUN'S SEMID.	EQUATION OF TIME.	VAR. IN ONE HOUR.
1887.	° ′ ″	″	° ′ ″	′ ″	M S	S
May 24	N.20 45 38·4	27·88	N.20 45 40·0	15 49·4	— 3 25·72	0·222
25	20 56 36·9	26·99	20 56 38·4	15 49·2	3 20·13	0·243
26	21 7 13·9	26·09	21 7 15·3	15 49·1	3 14·06	0·263
27	21 17 29·0	25·17	21 17 30·3	15 48·9	3 7·50	0·282
28	21 27 21·9	24·24	21 27 23·2	15 48·7	3 0·49	0·301
29	21 36 52·6	23·31	21 36 53·8	15 48·6	2 53·05	0·319
30	21 46 0·8	22·37	21 46 1·8	15 48·5	2 45·18	0·336
31	21 54 46·3	21·42	21 54 47·2	15 48·3	2 36·90	0·353
June 1	22 3 8·8	20·46	22 3 9·6	15 48·2	2 28·23	0·370
2	22 11 8·3	19·49	22 11 9·0	15 48·1	2 19·17	0·385
3	22 18 44·5	18·52	22 18 45·1	15 47·9	2 9·73	0·400
4	22 25 57·3	17·54	22 25 57·8	15 47·8	1 59·94	0·415
5	22 32 46·6	16·56	22 32 47·0	15 47·7	1 49·80	0·429
6	22 39 12·2	15·57	22 39 12·6	15 47·6	1 39·33	0·443
7	22 45 14·0	14·58	22 45 14·4	15 47·5	1 28·55	0·456
8	22 50 51·9	13·58	22 50 52·2	15 47·4	1 17·46	0·468
9	22 56 5·8	12·58	22 56 6·0	15 47·3	1 6·09	0·479
10	23 0 55·5	11·57	23 0 55·7	15 47·1	0 54·45	0·490
11	23 5 21·0	10·55	23 5 21·1	15 47·0	0 42·57	0·500
12	23 9 22·1	9·54	23 9 22·2	15 46·9	0 30·46	0·509
13	23 12 58·8	8·52	23 12 58·9	15 46·9	0 18·15	0·517
14	23 16 10·9	7·49	23 16 11·0	15 46·8	— 0 5·65	0·524
15	23 18 58·5	6·47	23 18 58·5	15 46·7	+ 0 7·01	0·530
16	23 21 21·4	5·44	23 21 21·4	15 46·6	0 19·80	0·536
17	23 23 19·6	4·41	23 23 19·6	15 46·5	0 32·71	0·540
18	23 24 53·1	3·38	23 24 53·1	15 46·4	0 45·72	0·543
19	23 26 1·8	2·35	23 26 1·8	15 46·4	0 58·79	0·545
20	23 26 45·7	1·31	23 26 45·7	15 46·3	1 11·89	0·546
21	23 27 4·9	0·28	23 27 4·9	15 46·3	1 25·01	0·546
22	23 26 59·2	0·75	23 26 59·2	15 46·2	1 38·11	0·545
23	23 26 28·8	1·79	23 26 28·8	15 46·2	1 51·15	0·542
24	23 25 33·5	2·82	23 25 33·6	15 46·1	2 4·11	0·538
25	23 24 13·6	3·85	23 24 13·7	15 46·1	2 16·97	0·533
26	23 22 28·9	4·88	23 22 29·1	15 46·1	2 29·69	0·527
27	23 20 19·5	5·90	23 20 19·8	15 46·0	2 42·25	0·519
28	23 17 45·6	6·93	23 17 45·9	15 46·0	2 54·62	0·511
29	23 14 47·0	7·95	23 14 47·4	15 46·0	3 6·79	0·502
30	23 11 24·0	8·97	23 11 24·5	15 46·0	3 18·73	0·493
July 1	23 7 36·6	9·98	23 7 37·2	15 46·0	3 30·42	0·482
2	23 3 24·9	10·99	23 3 25·6	15 46·0	3 41·85	0·470
3	22 58 49·1	11·99	22 58 49·9	15 46·0	3 53·00	0·458
4	22 53 49·2	12·99	22 53 50·1	15 46·0	4 3·85	0·445
5	22 48 25·4	13·99	22 48 26·4	15 46·0	4 14·38	0·432
6	22 42 37·9	14·97	22 42 39·0	15 46·0	4 24·57	0·418
7	22 36 26·7	15·96	22 36 27·9	15 46·0	4 34·42	0·403
8	22 29 52·0	16·93	22 29 53·3	15 46·1	4 43·90	0·387
9	22 22 54·0	17·90	22 22 55·4	15 46·1	4 53·00	0·371
10	22 15 32·7	18·86	22 15 34·3	15 46·1	5 1·71	0·354
11	22 7 48·5	19·82	22 7 50·2	15 46·1	5 10·01	0·337
12	21 59 41·4	20·77	21 59 43·2	15 46·2	5 17·89	0·319
13	21 51 11·6	21·71	21 51 13·5	15 46·2	5 25·33	0·301
14	21 42 19·3	22·64	21 42 21·4	15 46·3	5 32·32	0·282
15	21 33 4·7	23·56	21 33 7·0	15 46·3	5 38·85	0·262
16	21 23 28·2	24·48	21 23 30·5	15 46·4	5 44·90	0·242
17	21 13 29·8	25·39	21 13 32·2	15 46·4	5 50·46	0·221
18	N.21 3 9·7	26·28	N.21 3 12·3	15 46·5	+ 5 55·51	0·200

Apparent Noon. (N.A , p. I.)			Mean Noon. (N.A., p. II.)			
DATE.	DECLINATION.	VAR. IN ONE HOUR.	DECLINATION.	SUN'S SEMID.	EQUATION OF TIME.	VAR. IN ONE HOUR.
1887.	° ′ ″	″	° ′ ″	′ ″	M S	S
July 19	N.20 52 28·3	27·17	N.20 52 31·0	15 46·5	+ 6 0·04	0·178
20	20 41 25·7	28·04	20 41 28·5	15 46·6	6 4·03	0·155
21	20 30 2·2	28·91	20 30 5·2	15 46·7	6 7·47	0·131
22	20 18 18·2	29·76	20 18 21·2	15 46·8	6 10·34	0·107
23	20 6 13·7	30·61	20 6 16·8	15 46·9	6 12·63	0·083
24	19 53 49·0	31·44	19 53 52·3	15 47·0	6 14·32	0·058
25	19 41 4·5	32·26	19 41 7·9	15 47·1	6 15·42	0·033
26	19 28 0·4	33·07	19 28 3·8	15 47·2	6 15·90	0·007
27	19 14 36·9	33·88	19 14 40·5	15 47·3	6 15·77	0·018
28	19 0 54·3	34·67	19 0 58·0	15 47·4	6 15·03	0·044
29	18 46 53·0	35·44	18 46 56·7	15 47·5	6 13·67	0·070
30	18 32 33·2	36·21	18 32 36·9	15 47·6	6 11·68	0·096
31	18 17 55·1	36·96	18 17 58·9	15 47·8	6 9·08	0·121
Aug. 1	18 2 59·1	37·70	18 3 2·9	15 47·9	6 5·86	0·147
2	17 47 45·5	38·43	17 47 49·3	15 48·0	6 2·03	0·173
3	17 32 14 5	39·15	17 32 18·3	15 48·1	5 57·58	0·198
4	17 16 26·4	39·85	17 16 30·3	15 48·3	5 52·53	0·223
5	17 0 21·5	40·55	17 0 25·4	15 48·4	5 46·88	0·248
6	16 44 0·1	41·23	16 44 4·0	15 48·5	5 40·64	0·272
7	16 27 22·4	41·90	16 27 26·3	15 48·7	5 33·81	0·296
8	16 10 28·8	42·56	16 10 32·7	15 48·8	5 26·41	0·320
9	15 53 19·5	43·21	15 53 23·4	15 49·0	5 18·43	0·344
10	15 35 54·9	43·84	15 35 58·7	15 49·1	5 9·89	0·367
11	15 18 15·2	44·46	15 18 18·9	15 49·3	5 0·80	0·390
12	15 0 20·7	45·07	15 0 24·4	15 49·5	4 51·17	0·413
13	14 42 11·8	45·66	14 42 15·4	15 49·6	4 41·00	0·435
14	14 23 48·8	46·25	14 23 52·2	15 49·8	4 30·30	0·457
15	14 5 11·9	46·82	14 5 15·3	15 50·0	4 19·08	0·478
16	13 46 21·5	47·37	13 46 24·8	15 50·1	4 7·35	0·500
17	13 27 18·0	47·91	13 27 21·1	15 50·3	3 55·10	0·521
18	13 8 1·6	48·44	13 8 4·6	15 50·5	3 42·35	0·542
19	12 48 32·7	48·96	12 48 35·6	15 50·7	3 29·10	0·562
20	12 28 51 6	49·46	12 28 54·3	15 50·9	3 15·36	0·582
21	12 8 58·7	49·95	12 9 1·2	15 51·1	3 1·13	0·602
22	11 48 54·2	50·42	11 48 56·5	15 51·3	2 46·43	0·622
23	11 28 38·5	50·88	11 28 40·6	15 51·5	2 31·27	0·641
24	11 8 11·9	51·33	11 8 13·9	15 51·7	2 15·65	0·660
25	10 47 34·8	51·76	10 47 36·6	15 52·0	1 59·59	0·678
26	10 26 47·5	52·18	10 26 49·0	15 52·2	1 43·11	0·695
27	10 5 50·3	52·58	10 5 51·6	15 52·4	1 26·21	0·712
28	9 44 43·6	52·97	9 44 44·6	15 52·6	1 8·92	0·728
29	9 23 27·7	53·35	9 23 28·4	15 52·8	0 51·25	0·744
30	9 2 2·8	53·71	9 2 3·3	15 53·1	0 33·22	0·758
31	8 40 29·4	54·07	8 40 29·6	15 53·3	+ 0 14·85	0·772
Sept. 1	8 18 47·6	54·41	8 18 47·5	15 53·5	− 0 3·85	0·785
2	7 56 57·9	54·73	7 56 57·5	15 53·8	0 22·85	0·797
3	7 35 0·5	55·05	7 34 59·8	15 54·0	0 42·13	0·809
4	7 12 55·7	55·35	7 12 54·7	15 54·2	1 1·68	0·819
5	6 50 43·8	55 64	6 50 42·5	15 54·5	1 21·46	0 829
6	6 28 25·1	55·91	6 28 23·5	15 54·7	1 41·46	0·837
7	6 6 0·0	56·17	6 5 58·1	15 54·9	2 1·65	0·845
8	5 43 28·7	56·43	5 43 26·5	15 55·2	2 22·02	0·852
9	5 20 51·6	56·66	5 20 49·1	15 55·4	2 42·54	0·858
10	4 58 9·0	56·88	4 58 6·1	15 55·6	3 3·20	0·863
11	4 35 21·2	57·09	4 35 17·9	15 55·9	3 23·98	0·867
12	N. 4 12 28·5	57·29	N. 4 12 24·9	15 56·2	− 3 44·85	0·871

Apparent Noon. (N.A., p. I.)			Mean Noon. (N.A., p. II.)			
DATE.	DECLINATION.	VAR. IN ONE HOUR.	DECLINATION.	SUN'S SEMID.	EQUATION OF TIME.	VAR. IN ONE HOUR.
1887.	° ′ ″	″	° ′ ″	′ ″	M S	S
Sept. 13	N. 3 49 31·4	57·47	N. 3 49 27·4	15 56·4	— 4 5·80	0·874
14	3 26 30·0	57·64	3 26 25·7	15 56·7	4 26·82	0·876
15	3 3 24·8	57·79	3 3 20·2	15 56·9	4 47·88	0·878
16	2 40 16·1	57·93	2 40 11·1	15 57·2	5 8·97	0·879
17	2 17 4·2	58·05	2 16 58·9	15 57·4	5 30·08	0·879
18	1 53 49·6	58·16	1 53 43·9	15 57·7	5 51·19	0·879
19	1 30 32·5	58·26	1 30 26·4	15 58·0	6 12·27	0·878
20	1 7 13·2	58·34	1 7 6·8	15 58·2	6 33·33	0·876
21	0 43 52·3	58·40	0 43 45·5	15 58·5	6 54·33	0·874
22	N. 0 20 30·0	58·45	N. 0 20 22·9	15 58·8	7 15·26	0·870
23	S. 0 2 53·4	58·49	S. 0 3 0·8	15 59·1	7 36·11	0·866
24	0 26 17·4	58·51	0 26 25·1	15 59·3	7 56·85	0·861
25	0 49 41·7	58·51	0 49 49·8	15 59·6	8 17·46	0·856
26	1 13 5·9	58·50	1 13 14·4	15 59·9	8 37·93	0·849
27	1 36 29·8	58·48	1 36 38·6	16 0·2	8 58·22	0·842
28	1 59 52·9	58·44	2 0 2·0	16 0·5	9 18·33	0·833
29	2 23 15·0	58·39	2 23 24·4	16 0·7	9 38·22	0·824
30	2 46 35·7	58·33	2 46 45·4	16 1·0	9 57·88	0·813
Oct. 1	3 9 54·7	58·25	3 10 4·7	16 1·3	10 17·27	0·802
2	3 33 11·6	58·15	3 33 21·9	16 1·6	10 36·37	0·789
3	3 56 26·1	58·05	3 56 36·6	16 1·8	10 55·16	0·776
4	4 19 37·9	57·93	4 19 48·7	16 2·1	11 13·62	0·762
5	4 42 46·6	57·79	4 42 57·7	16 2·4	11 31·72	0·746
6	5 5 51·9	57·64	5 6 3·3	16 2·7	11 49·44	0·730
7	5 28 53·5	57·48	5 29 5·1	16 2·9	12 6·75	0·713
8	5 51 50·9	57·30	5 52 2·7	16 3·2	12 23·64	0·695
9	6 14 43·9	57·11	6 14 55·9	16 3·5	12 40·09	0·676
10	6 37 32·0	56·90	6 37 44·3	16 3·8	12 56·07	0·656
11	7 0 14·9	56·67	7 0 27·4	16 4·0	13 11·56	0·635
12	7 22 52·3	56·43	7 23 4·9	16 4·3	13 26·55	0·614
13	7 45 23·7	56·18	7 45 36·5	16 4·6	13 41·03	0·592
14	8 7 48·7	55·90	8 8 1·7	16 4·8	13 54·96	0·569
15	8 30 7·0	55·61	8 30 20·1	16 5·1	14 8·35	0·546
16	8 52 18·1	55·31	8 52 31·4	16 5·4	14 21·17	0·522
17	9 14 21·8	54·99	9 14 35·1	16 5·7	14 33·41	0·498
18	9 36 17·5	54·65	9 36 30·9	16 5·9	14 45·05	0·473
19	9 58 4·9	54·29	9 58 18·4	16 6·2	14 56·09	0·447
20	10 19 43·5	53·92	10 19 57·1	16 6·5	15 6·51	0·421
21	10 41 12·9	53·53	10 41 26·5	16 6·7	15 16·30	0·395
22	11 2 32·7	53·12	11 2 46·4	16 7·0	15 25·45	0·368
23	11 23 42·6	52·69	11 23 56·2	16 7·3	15 33·94	0·340
24	11 44 42·0	52·25	11 44 55·6	16 7·6	15 41·76	0·312
25	12 5 30·5	51·79	12 5 44·2	16 7·8	15 48·90	0·283
26	12 26 7·9	51·31	12 26 21·5	16 8·1	15 55·34	0·254
27	12 46 33·6	50·82	12 46 47·2	16 8·4	16 1·07	0·224
28	13 6 47·4	50·32	13 7 0·9	16 8·6	16 6·06	0·193
29	13 26 48·8	49·79	13 27 2·2	16 8·9	16 10·31	0·161
30	13 46 37·3	49·25	13 46 50·7	16 9·2	16 13·80	0·129
31	14 6 12·8	48·70	14 6 26·0	16 9·4	16 16·51	0·097
Nov. 1	14 25 34·7	48·12	14 25 47·7	16 9·7	16 18·43	0·064
2	14 44 42·6	47·53	14 44 55·5	16 9·9	16 19·55	0·030
3	15 3 36·2	46·93	15 3 49·0	16 10·1	16 19·85	0·004
4	15 22 15·1	46·31	15 22 27·7	16 10·4	16 19·33	0·039
5	15 40 38·9	45·67	15 40 51·3	16 10·6	16 17·97	0·074
6	15 58 47·2	45·01	15 58 59·4	16 10·8	16 15·77	0·109
7	S. 16 16 39·6	44·34	S. 16 16 51·6	16 11·1	— 16 12·71	0·145

Apparent Noon. (N.A., p. I).			Mean Noon. (N.A., p. II).			
DATE.	DECLINATION.	VAR. IN ONE HOUR.	DECLINATION.	SUN'S SEMID.	EQUATION OF TIME.	VAR. IN ONE HOUR.
1887.	° ′ ″	″	° ′ ″	′ ″	M S	S
Nov. 8	S. 16 34 15·6	43·65	S. 16 34 27·4	16 11·3	— 16 8·80	0·180
9	16 51 35·0	42·95	16 51 46·5	16 11·5	16 4·03	0·216
10	17 8 37·2	42·23	17 8 48·5	16 11·8	15 58·40	0·252
11	17 25 21·9	41·49	17 25 32·9	16 12·0	15 51·90	0·289
12	17 41 48·7	40·73	17 41 59·4	16 12·2	15 44·53	0·325
13	17 57 57·1	39·96	17 58 7·5	16 12·4	15 36·30	0·361
14	18 13 46·8	39·17	18 13 56·9	16 12·6	15 27·21	0·396
15	18 29 17·4	38·37	18 29 27·2	16 12·9	15 17·26	0·432
16	18 44 28·4	37·54	18 44 37·9	16 13·1	15 6·46	0·467
17	18 59 19·5	36·70	18 59 28·6	16 13·3	14 54·83	0·501
18	19 13 50·2	35·84	19 13 59·0	16 13·5	14 42·37	0·536
19	19 28 0·1	34·97	19 28 8·6	16 13·7	14 29·11	0·569
20	19 41 48·9	34·08	19 41 57·0	16 13·9	14 15·04	0·603
21	19 55 16·1	33·18	19 55 23·8	16 14·1	14 0·18	0·635
22	20 8 21·4	32·26	20 8 28·8	16 14·3	13 44·54	0·668
23	20 21 4·4	31·32	20 21 11·4	16 14·5	13 28·13	0·700
24	20 33 24·8	30·37	20 33 31·5	16 14·6	13 10·95	0·731
25	20 45 22·2	29·41	20 45 28·5	16 14·8	12 53·03	0·762
26	20 56 56·3	28·43	20 57 2·3	16 15·0	12 34·37	0·793
27	21 8 6·8	27·44	21 8 12·4	16 15·2	12 14·98	0·822
28	21 18 53·4	26·43	21 18 58·6	16 15·3	11 54·89	0·852
29	21 29 15·7	25·42	21 29 20·6	16 15·5	11 34·09	0·881
30	21 39 13·5	24·39	21 39 18·1	16 15·7	11 12·61	0·909
Dec. 1	21 48 46·6	23·35	21 48 50·8	16 15·8	10 50·47	0·936
2	21 57 54·5	22·30	21 57 58·4	16 16·0	10 27·68	0·963
3	22 6 37·1	21·24	22 6 40·7	16 16·1	10 4·26	0·989
4	22 14 54·1	20·17	22 14 57·3	16 16·2	9 40·24	1·014
5	22 22 45·2	19·09	22 22 48·1	16 16·4	9 15·62	1·038
6	22 30 10·2	17·99	22 30 12·8	16 16·5	8 50·44	1·061
7	22 37 8·9	16·89	22 37 11·2	16 16·6	8 24·72	1·083
8	22 43 41·0	15·78	22 43 43·0	16 16·7	7 58·49	1·104
9	22 49 46·2	14·66	22 49 48·1	16 16·8	7 31·76	1·124
10	22 55 24·5	13·53	22 55 26·1	16 17·0	7 4·57	1·142
11	23 0 35·7	12·40	23 0 37·0	16 17·1	6 36·95	1·160
12	23 5 19·5	11·26	23 5 20·7	16 17·2	6 8·92	1·176
13	23 9 35·9	10·10	23 9 36·8	16 17·3	5 40·53	1·190
14	23 13 24·5	8·95	23 13 25·3	16 17·3	5 11·81	1·203
15	23 16 45·4	7·79	23 16 46·0	16 17·4	4 42·80	1·214
16	23 19 38·5	6·63	23 19 38·9	16 17·5	4 13·54	1·224
17	23 22 3·5	5·45	23 22 3·8	16 17·6	3 44·07	1·232
18	23 24 0·3	4·28	23 24 0·6	16 17·7	3 14·42	1·238
19	23 25 29·0	3·11	23 25 29·2	16 17·8	2 44·64	1·243
20	23 26 29·4	1·93	23 26 29·5	16 17·8	2 14·76	1·247
21	23 27 1·5	0·75	23 27 1·5	16 17·9	1 44·82	1·249
22	23 27 5·3	0·43	23 27 5·2	16 18·0	1 14·85	1·249
23	23 26 40·7	1·62	23 26 40·6	16 18·0	0 44·88	1·249
24	23 25 47·7	2·80	23 25 47·7	16 18·1	— 0 14·94	1·246
25	23 24 26·5	3·97	23 24 26·5	16 18·1	+ 0 14·93	1·243
26	23 22 37·0	5·15	23 22 37·1	16 18·1	0 44·70	1·238
27	23 20 19·3	6·33	23 20 19·4	16 18·2	1 14·34	1·232
28	23 17 33·4	7·50	23 17 33·7	16 18·2	1 43·81	1·225
29	23 14 19·5	8·66	23 14 19·9	16 18·2	2 13·09	1·216
30	23 10 37·7	9·82	23 10 38·1	16 18·2	2 42·15	1·206
31	23 6 28·0	10·98	23 6 28·6	16 18·3	3 10·95	1·195
1888. Jan. 1	S. 23 1 50·6	12·13	S. 23 1 51·3	16 18·3	+ 3 39·47	1·182

DECLINATION OF FIXED STARS.

DATE.	STAR'S NAME.	DECLINATION.	DATE.	STAR'S NAME.	DECLINATION.
1887.		° ′ ″	1887.		° ′ ″
January 1	Capella ……	45 52 50 N.	June 15	α Serpentis ..	6 46 58 N.
„ 1	Sirius ……	16 33 54 S.	„ 16	η Argus ……	59 5 50 S.
„ 8	Vega ……	38 40 48 N.	„ 17	α Serpentis ..	6 46 58 N.
„ 24	Aldebaran ….	16 16 44 N.	July 6	Antares ……	26 10 48 S.
February 1	Sirius ……	16 34 0 S.	„ 17	α Cygni ……	44 52 45 N.
„ 2	Aldebaran ….	16 16 44 N.	„ 19	α Pavonis ….	57 5 30 S.
„ 12	Procyon ……	5 30 37 N.	August 7	Antares ……	26 10 49 S.
March 2	Sirius ……	16 34 4 S.	„ 19	Vega ……	38 41 6 N.
„ 11	Canopus ….	52 38 30 S.	„ 20	Altair ……	8 34 32 N.
„ 12	Pollux ……	28 17 47 N.	„ 20	β Centauri ….	59 49 54 S.
„ 19	Arcturus ….	19 46 9 N.	Sept. 7	Arcturus ….	19 46 23 N.
„ 31	Spica ……	10 34 22 S.	„ 11	α Cassiopeiæ ..	55 55 10 N.
„ 31	α Pegasi ….	14 35 44 N.	October 7	Markab ……	14 36 12 N.
April 3	Arcturus ….	19 46 10 N.	„ 8	α Gruis ……	47 30 21 S.
„ 11	Spica ……	10 34 23 S.	„ 17	α Aquilæ ….	8 34 34 N.
„ 11	Sirius ……	16 34 4 S.	„ 29	α Piscis [Australis ..	30 13 5 S.
„ 12	Spica ……	10 34 23 S.			
May 1	α ^{2}Centauri ..	60 22 1 S.	Nov. 7	Fomalhaut ..	30 13 7 S.
„ 10	Spica ……	10 34 23 S.	„ 7	α Andromedæ.	28 28 23 N.
„ 10	α ^{2}Centauri ..	60 22 3 S.	„ 30	α Arietis ….	22 55 55 N.
„ 16	β Orionis ….	8 20 11 S.	Dec. 7	α Arietis ….	22 55 55 N.
„ 18	η ^{2}Draconis ..	61 46 14 N.	„ 21	Procyon ……	5 30 35 N.
„ 22	α Hydræ ….	8 10 23 S.	„ 21	α Cygni(*Deneb*)	44 53 0 N.
June 1	α ^{1}Crucis ….	62 28 42 S.	„ 22	α Persei ……	49 27 44 N.
„ 10	α Cassiopeiæ ..	55 54 49 N.	„ 27	Algenib ……	14 33 38 N.
„ 10	Achernar ….	57 48 25 S.	„ 29	Regulus ……	12 30 48 N.
„ 11	Pollux ……	28 17 49 N.			

ADMIRALTY TIDE TABLES FOR 1885.

DATE.	NAME OF PORT.	STANDARD PORT FOR REFERENCE.	FULL AND CHANGE.	SPRING RANGE.	CONSTANTS		MORNING.	HEIGHT.	AFTERNOON.	HEIGHT.	MOON'S TRANSIT.
					TIME.	HEIGHT					
1885			h m	ft in	h m	ft in	h m	ft in	h m	ft in	h m
Jan. 6	Bordeaux …………	Brest …………			+ 3 3		7 20		7 43		
7	Needles …………	Portsmouth ………			— 1 55		3 42		4 4		
11	Maryport …………	Liverpool …………			+ 0 3		7 27		8 2		
15	Scarborough ………	Sunderland ………			+ 0 49		3 25		3 42		
19	Cherbourg ………	Brest …………			+ 4 2		5 27		5 41		
19	Falmouth …………	Devonport …………			— 0 46		7 21		7 37		
19	Christchurch ………	Portsmouth ………			— 2 41		1 9		1 26		
20	„ ………	………					1 45		2 3		
21	Sandy Hook ………	Brest …………	7 29	5 6			6 39	17 9	6 59	17 4	4 4
22	„ ………	„ …………									4 52
29	Aberdeen …………	Leith …………			— 1 17		0 49		1 16		
29	Montrose…………	„ …………			— 0 52		0 49		1 16		
29	Ramsgate …………	London …………			— 2 19		0 12		0 44		
30	„ …………	„ …………					1 12		1 39		
29	Fecamp …………	Brest …………			+ 6 57		2 21		2 47		
29	Chatham…………	Sheerness …………			+ 0 18		11 27		11 54		
Feb. 1	Orfordness ………	Harwich …………			— 0 51		0 47		1 10		
1	Loch Ryan…………	Greenock…………			— 0 56		0 49		1 12		
1	Peel …………	Holyhead …………			+ 0 57		11 12		11 32		
1	Warren Point ……	Kingstown …………			— 0 2		——		0 11		
1	St. Ives …………	Weston-super-mare		21 0	— 2 10		7 58	39 9	8 19	39 7	
1	Weston-super-mare	…………	6 54	37 0							
2	Cardigan…………	Holyhead …………			— 3 10		11 53		——		
3	„ …………	„ …………					0 14		0 36		
8	Filey Bay …………	Sunderland ………			+ 0 58		9 42		10 17		
8	Milford Haven ……	Pembroke …………			— 0 16		——		0 8		
8	Cromarty …………	Leith …………			— 2 21		8 46		9 23		
7	Calcutta …………	Brest …………	2 0	17 0			9 2		9 32		6 13

DATE.	NAME OF PORT.	STANDARD PORT FOR REFERENCE.	FULL AND CHANGE.	SPRING RANGE.	CONSTANT		MORNING.	HEIGHT.	AFTERNOON.	HEIGHT.	MOON'S TRANSIT.
					TIME.	HEIGHT.					
1885			h m	ft in	h m	ft in	h m	ft in	h m	ft in	h m
Feb. 8	Brest		3 47	19 0			10 6		10 44		6 59
8	Penzance	Devonport			— 1 13		11 30		——		
9	„	„					0 4		0 41		
10	Blyth	Sunderland			— 0 7		——		0 7		
27	San Francisco	Brest	0 6	4 3			2 12		2 37		11 8
28	„	„					3 1		3 24		——
Mar. 1	„	„					3 46		4 7		0 1
Feb 28	Strangford Quay	Kingstown			+ 1 19		10 29		10 50		
Mar. 1	„	„					11 10		11 30		
1	Newhaven	Dover			+ 0 39		11 11		11 34		
1	Bembridge Point	Portsmouth			— 0 41		11 42		——		
2	„	„					0 3		0 24		
1	Lamlash	Greenock			— 0 19		——		0 8		
2	„	„					0 30		0 51		
1	Hurst Camber	Portsmouth			— 1 41		11 42		——		
2	„	„					0 3		0 24		
3	Quillebeauf	Brest			+ 6 19		5 7		5 25		
4	„	„					5 43		6 1		
4	Havre	„			+ 5 31		5 43		6 1		
3	Lerwick	Thurso			+ 2 2		9 47		10 7		
4	„	„					10 26		10 45		
4	Poole	Portsmouth			— 2 31		1 25		1 41		
5	„	„					2 3		2 21		
4	Yarmouth Road	Harwich			— 2 51		1 52		2 11		
5	„	„					2 30		2 49		
4	Beaumaris	Liverpool			— 0 55		1 2		1 20		
24	Exmouth	Devonport			+ 0 36		11 3		11 39		
25	„	„					——		0 20		
25	Penzance	„			— 1 13		——		0 20		
26	„	„					1 5		1 49		
April 3	Aberdovey	Holyhead			— 2 11		——		0 14		
4	„	„					0 33		0 52		
3	Port Patrick	Greenock			— 0 58		1 58		2 15		
3	Arklow	Kingstown			— 3 12		0 59		1 17		
4	„	„					1 35		1 53		
3	Ballycastle Bay	Belfast			— 4 18		0 34		0 52		
4	„	„					1 11		1 31		
7	Ecrehous	Brest			+ 2 45		8 32		9 4		
8	„	„					9 41		10 22		
8	Blakeney Bar	Hull			+ 0 1		——		0 26		
8	Portree	Thurso			— 1 56		2 8		2 49		
8	Llanelly	Pembroke			+ 0 4		11 45		——		
8	Cardiff	Weston-super-mare			+ 0 2		——		0 20		
8	New Ross	Waterford			+ 0 44		11 5		11 42		
9	Hobart	Brest	8 15				11 2		11 41		7 27
10	„	„					——		0 18		8 14
9	Morlaix	„			+ 1 6		11 2		11 41		
10	„	„					——		0 1[illegible]		
10	Ile de Sein	„			— 0 2[illegible]		——		0 18		
9	Ecrehous	„			+ 2 45		11 2		11 41		
10	„	„					——		0 18		
10	Penzance	Devonport			— 1 13		0 58		1 38		
10	Limerick	Galway			+ 1 35		0 41		1 14		
10	Dunmanus Harb'r	Queenstown			— 1 4		0 40		1 16		
10	Caracus	Brest	3 30				——		0 18		8 14
11	„	„					0 50		1 18		9 0
15	Ramsey (I. of Man)	Holyhead		20 9	+ 1 1	+ 3 3	10 3	16 4	10 21	16 6	
22	Lyme Regis	Devonport			+ 0 38		10 56		11 30		
22	New Ross	Waterford			+ 0 44		10 44		11 22		
23	„	„					——		Noon		
23	Dunmore	„			+ 0 7		——		Noon		
23	Ballycotton	„			— 0 26		——		Noon		
May 2	Lerwick	Thurso			+ 2 2		10 6		10 24		
3	„	„					10 42		11 1		
6	Portland B'water	Portsmouth			— 4 40		3 37		4 1		
7	„	„					4 27		4 56		
8	Cherbourg	Brest			+ 4 2		10 [illegible]		10 45		
9	„	„					11 21		11 55		
29	Tarn Point	Liverpool			— 0 1		11 29		11 47		
29	Berwick	Sunderland			— 1 4		3 31		3 49		
29	St. Malo	Brest			+ 2 18		3 54		4 12		
29	Dungeness	Dover			— 0 27		11 21		11 41		
29	Loch Ryan	Greenock			— 0 56		——		0 17		
30	„	„					0 36		0 54		

DATE.	NAME OF PORT.	STANDARD PORT FOR REFERENCE.	FULL AND CHANGE.	SPRING RANGE.	CONSTANTS		MORNING.	HEIGHT.	AFTERNOON.	HEIGHT.	MOON'S TRANSIT.
					TIME.	HEIGHT.					
1885			h m	ft in	h m	ft in	h m	ft in	h m	ft in	h m
May 29	Boulogne	Dover			+ 0 13		11 21		11 41		
30	"	"					—		noon		
31	Ballycastle Bay	Belfast			— 4 18		—		0 4		
June 1	"	"					0 22		0 41		
3	Barfleur	Brest	8 59	17 0	+ 5 4	— 1 0	6 51	15 10	7 12	15 6	
5	Bombay	"	11 40				8 22		8 49		5 32
6	"	"					9 19		9 51		6 17
5	Coleraine	Londonderry			— 1 37		0 29		1 3		
6	Cardigan	Holyhead			— 3 10		3 33		4 5		
6	Bridgewater Bar	Weston-super-mare			— 0 4		11 59		—		
6	Jersey	Brest			+ 2 42		9 19		9 51		
6	Littlehampton	Portsmouth			— 0 5		4 45		5 13		
6	Limerick	Galway		18 9	+ 1 35	+ 3 2	10 23	10 11	10 56	11 0	
7	Tenby	Pembroke		27 0	— 0 30	+ 5 3	—	—	0 23	16 0	
8	Scarborough	Sunderland		15 9	+ 0 49	+ 1 5	11 5	11 6	11 34	11 9	
8	St. Mary's	Devonport		16 0	— 1 16	+ 0 6	0 29	12 7	1 7	12 7	
8	Guernsey	Brest		26 0	+ 2 50		11 32	14 10	—	—	
8	Avatcha Bay	"	3 30				11 32		—		7 3
9	"	"					0 4		0 34		7 51
10	Rochelle	"	3 5	17 0			1 3	16 6	1 30	17 2	
12	Valentia	Queenstown		11 0	— 1 19	— 0 8	3 58	11 8	4 24	11 11	
12	Ilfracombe	Weston-super-mare		27 3	— 1 12		5 50	37 0	6 18	37 8	
14	Lerwick	Thurso		6 0	+ 2 2		9 7	14 0	9 32	13 10	
14	Thurso			13 3							
14	Christchurch	Portsmouth		5 0	— 2 41		—	—	0 24	14 0	
14	Portsmouth			13 6							
14	Needles	Portsmouth		7 6	— 1 55	— 6 0	—	—	0 24	14 0	
14	Lizard	Devonport	5 0	14 3			6 21	16 1	6 46	16 6	
14	Devonport		5 43	15 6							
16	Aberystwyth	Holyhead	7 31	13 6	— 2 40	— 2 6	0 4	16 4	0 31	16 1	
17	"	"					0 59	15 9			
16	Brest		3 47	19 0					6 29	18 10	
17	Devonport		5 43	15 6			8 44	15 0	9 8	15 3	
17	Port Jackson	Brest	8 15				6 55		7 21		4 30
18	"	"					7 48		8 15		5 22
18	Inishbofin	Sligo	4 34	12 3			9 26	9 8	9 58	9 5	
18	Sligo		5 18	11 3							
19	Portland Br'kwater	Portsmouth			— 4 40		4 14		4 40		
19	Maiden Rocks	Belfast	10 43	6 9			3 35	8 9	4 5	8 7	
19	Belfast		10 43	9 6							
18	Inishbofin	Sligo	4 34	12 3			9 26	9 8	9 58	9 5	
19	Tuscar	Waterford	5 45	9 0			10 7	11 2	10 37	10 10	
	Waterford		5 20	12 6							
20	Lyme Regis	Devonport			+ 0 38		11 15		11 46		
20	Hurst Camber	Portsmouth			— 1 41		5 7		5 36		
20	St. Malo	Brest			+ 2 18		9 42		10 15		
20	Ilfracombe	Weston-super-mare			— 1 12		—		0 22		
21	Ile de Bas	Brest	4 49	23 0			10 50	14 8	11 25	14 7	
22	"	"					11 58	14 9	—	—	
21	Orinan	Greenock			+ 4 41	— 4 4	6 33	8 7	7 6	8 6	
22	"	"					7 38	8 6	8 10	8 6	
22	Flambro' Head	Hull			— 1 59		2 6		2 36		
22	Peterhead	Leith			— 1 43		10 35		11 4		
22	St. Ives	Weston-super-mare			— 2 10		1 59		2 33		
22	Cape Wrath	Thurso			— 0 58		4 36		5 6		
22	Whitby	Sunderland			+ 0 23		11 29		11 58		
23	Belle Ile	Brest			— 0 29		0 29		0 59		
26	Heligoland	Harwich	11 33	9 3	— 0 33	— 2 3	11 21	10 11	11 42	11 0	
30	Lowestoft	"			— 2 9		1 37		1 47		
July 1	"	"					2 5		2 23		
7	Falmouth	Devonport			— 0 46		—		0 15		
8	"	"					0 54		1 34		
7	Skull	Queenstown			— 0 59		11 47		—		
8	"	"					0 21		0 56		
7	Kilrush	Galway			+ 0 7		11 50		—		
8	Madras	Brest	8 35	3 6			11 57	15 5	—	—	8 17
9	"	"					0 31	15 10	1 3	16 5	9 14
9	Noirmoutier	"			— 0 45		0 31		1 3		
9	Port Navalo	"			— 0 5		0 31		1 3		
9	Belle Ile	"			— 0 29		0 31		1 3		
9	Lynn Deep	Hull			— 0 29		3 5		3 36		
19	Ballycastle Bay	Belfast			— 4 18		3 57		4 26		
22	Scarborough	Sunderland	4 11	15 9	+ 0 49	+ 1 5	11 54	11 3	—	—	
23	"	"					0 24	11 5	0 53	11 7	

DATE.	NAME OF PORT.	STANDARD PORT FOR REFERENCE.	FULL AND CHANGE.	SPRING RANGE.	CONSTANTS.		MORNING.	HEIGHT.	AFTERNOON.	HEIGHT.	MOON'S TRANSIT.
					TIME.	HEIGHT.					
1885			h m	ft in	h m	ft in	h m	ft in	h m	ft in	h m
July 22	Hartlepool	Sunderland			+ 0 6		11 54	11 3	—	—	
31	Needles	Portsmouth		7 6	− 1 55	− 6 0	1 47	12 10	2 4	12 9	
Aug. 1	”	”					2 22	12 8	2 41	12 6	
July 31	Nelson	Brest	9 50	14 0			6 4	17 10	6 21	17 8	2 58
Aug. 1	”	”					39	17 4	6 59	16 11	3 43
July 31	Dieppe	”			+ 7 19		6 4		6 21		
Aug. 1	”	”					6 39		6 59		
1	Cape Virgin	”	8 30				6 39		6 59		
2	”	”					7 21		7 41		4 29
3	”	”									5 17
1	Stromness	Thurso			+ 0 32		11 29		11 50		
2	”	”					—		0 12		
4	Ilfracombe	Weston-super-mare			− 1 12		11 41		—		
5	”	”					0 11		0 46		
9	Flushing	Dover			+ 1 42		9 37		10 6		
10	”	”					10 34		11 2		
11	Lundy	Weston-super-mare	5 15	27 0			7 11	39 4	7 35	39 9	
11	Boulogne	Dover			+ 0 13				11 55		
12	”	”					—		0 19		
12	Lerwick	Thurso	10 30	6 0	+ 2 2		9 28	14 4	9 50	14 2	
18	New Ross	Waterford			+ 0 44		10 43		11 1		
19	”	”					11 49		—		
19	Tarbert	Galway			+ 0 22		11 35		—		
19	Skull	Queenstown			− 0 59		11 29		—		
20	”	”					0 8		0 47		
18	New York	Brest	7 29				9 16		9 50		
19	”	”					10 27		11 7		7 33
20	”	”					11 4		—		8 20
19	Oban	Greenock			+ 5 14		6 8		6 4		
20	”	”					7 23		8 1		
20	St Ives	Weston-super-mare			− 2 10		1 43		2 23		
20	Ile de Sein	Brest			− 0 26		11 48		—		
21	”	”					0 26		1 0		
20	Penzance	Devonport			− 1 13		0 25		1 4		
21	”	”					1 44		2 21		
22	Cadiz	Brest			− 1 51		1 28		1 52		
22	Arbroath	Leith			− 0 42		—		0 26		
23	”	”					0 48		1 8		
22	Dunbar	Sunderland			− 1 14		0 53		1 2		
22	Westport	Sligo			− 0 21		3 6		3 28		
26	Macao	Brest	10 0				3 59		4 16		0 11
27	”	”									0 5
27	Whitehaven	Liverpool			− 0 9		—		0 9		
28	Point de Galle	Brest	2 0				5 5		5 21		1 41
29	”	”					5 38		5 55		2 2
31	Barfleur	”			+ 5 4		6 52		7 14		
Sept. 1	”	”					7 38		8 4		
1	Padstow	Weston-super-mare			− 1 41		10 29		10 51		
1	Portland B'kwater.	Portsmouth			− 4 40		3 14		3 37		
2	”	”					4 2		4 32		
1	Bardsey Island	Holyhead			− 2 31		1 47		2 13		
2	”	”					2 42		3 15		
2	Wexford	Waterford			+ 2 1		9 59		10 32		
3	Alderney	Brest			+ 2 59		9 45		10 28		
4	”	”					11 14		11 59		
4	Heligoland	Harwich			− 0 33		6 32		7 16		
4	Nieuport	Dover			+ 1 6		5 50		6 20		
4	Fowey	Devonport			− 0 29		—		0 37		
4	Hastings	Dover			− 0 19		5 50		6 9		
4	Dornock Road	Leith			− 2 30		9 44		10 26		
4	Abervrach	Brest			+ 0 27		11 14		11 59		
5	”	”					—		0 37		
5	Ile de Aix	”			− 0 27		—		0 37		
5	Rotterdam	Dover			+ 4 33		7 11		7 1		
5	Porth-dyn-lleyn	Holyhead			− 1 41		6 39		7 14		
9	Inverary	Greenock			− 0 8		—		0 4		
19	Rio de Janeiro	Brest	3 0				—		0 22		8 35
20	”	”					0 54		1 2		9 21
26	Boulogne	Dover		25 3	+ 0 13	+ 5 4	—	—	0 12	19 1	
27	Liverpool		11 23	27 6			0 34	28 1	0 52	25 11	
Oct. 2	Torbay	Devonport			+ 0 17		11 3		11 43		
6	Gibraltar	Brest			− 2 0		1 53		2 1		
6	Berwick	Sunderland			− 1 4		1 21		1 49		

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					TIME.	HEIGHT.					
1885			h m	ft in	h m	ft in	h m	ft in	h m	ft in	h m
Oct. 6	Ramsgate	London			— 2 19		—		0 20		
7	"	"					0 44		1 7		
6	Wick	Leith			— 2 55		0 24		0 48		
7	"	"					1 11		1 32		
9	Wexford	Waterford		5 0	+ 2 1	— 7 4	5 39	13 0	5 58	13 0	
11	Southampton	Portsmouth			— 1 11		0 57		1 16		
15	Victoria River	Brest	7 15				7 55		8 23		5 42
16	"	"					8 55		9 32		6 29
17	Arcachon	"			+ 0 50		10 11		10 52		
18	"	"					11 32		—		
19	Bantry Harbour	Queenstown		10 0	— 1 14	— 1 7	1 6	9 1	1 38	9 4	
21	Cadiz	Brest			— 1 51		1 47		2 6		
Nov. 1	Milford Haven	Pembroke			— 0 16		0 3		0 44		
1	Ostende	Dover			+ 1 13		5 20		6 3		
1	East Looe	Devonport			— 0 17		—		0 17		
1	Spurn Point	Hull			— 1 3		0 44		1 23		
1	Ilfracombe	Weston-super-mare			— 1 12		0 40		1 21		
19	Crinan	Greenock			+ 4 41		9 19		9 42		
20	"	"					10 4		10 2[illegible]		
19	Batavia	Brest	10 0				1 6		1 29		9 42
20	"	"					1 50		2 10		10 33
20	Woolwich	London			— 0 21		—		0 20		
21	"	"					0 41		1 2		
20	Gibraltar	Brest			— 2 0		1 50		2 10		
20	Cromarty	Leith			— 2 21		0 25		0 45		
21	"	"					1 5		1 25		
26	Stromness	Thurso			+ 0 32		10 58		11 26		
27	"	"					11 55		—		
28	Filey Bay	Sunderland		16 0	+ 0 58	+ 1 6	7 35	12 10	8 7	12 6	
29	Sheep Haven	Sligo			+ 0 14		11 0		11 37		
30	"	"					—		0 13		
30	Yokohama	Brest	6 0				10 19		10 58		7 0
Dec 1	"	"					11 35		—		7 48
Nov. 30	Morlaix	"			+ 1 6		10 19		10 58		
Dec. 1	"	"					11 35		—		
Nov. 30	Arcachon	"			+ 0 50		10 19		10 58		
Dec. 1	"	"					11 35		—		
1	Falmouth	Devonport			— 0 46		0 30		1 9		
1	Bridlington	Hull			— 1 50		1 38		2 11		
1	Padstow	Weston-super-mare			— 1 41		1 34		2 10		
1	Cour macsherry	Queenstown			— 0 25		—		0 34		
Nov. 30	Port Royal	Brest	11 0				10 19		10 58		
Dec. 1	"	"					11 35		—		7 48
2	"	"									8 37
2	Skull	Queenstown			— 0 59		1 8		1 41		
2	Westport	Sligo			— 0 21		1 52		2 20		
2	Valentia	Queenstown			— 1 19		1 8		1 41		
2	Limerick	Galway			+ 1 35		1 4		1 32		
2	Coleraine	Londonderry			— 1 37		4 41		5 4		
2	Tenby	Pembroke			— 0 30		2 12		2 45		
8	Arklow Bank	Kingstown	8 0	3 6	— 3 12		11 57	10 6	—	—	
	Kingstown		11 12	11 3							
11	Lundy Island	Weston-super-mare		27 0	— 1 39		9 23	33 5	9 39	32 10	
13	Pwllheli	Holyhead			— 2 25		1 52		2 15		
14	"	"					2 40		3 8		
16	Arcachon	Brest			+ 0 50		10 35		11 10		
17	"	"					11 24		—		
16	Scarborough	Sunderland			+ 0 49		10 10		10 43		
17	"	"					11 15		11 45		
17	Holy Island	"			— 0 52		11 15		11 45		
17	Montrose	Leith			— 0 52		10 22		10 52		
16	Angra Pequena	Brest	2 30	8 0							7 30
17	"	"					11 44		—		8 19
18	"	"					0 17		0 47		
17	Santander	"			— 0 17		11 44		—		
18	"	"					0 17		0 47		
19	Aberdeen	Leith			— 1 17		—		0 13		
20	"	"					0 36		0 59		
23	Weston-super-mare		6 54	37 0			7 39	39 2	8 3	39 3	

NAUTICAL ACADEMY,

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